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Draughtsmen.

PROCESS PLANNING

By RAYMOND H. DIPPLE. Grad.I.P.E.

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PROCESS PLANNING.

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INTRODUCTION.

PROCESS planning, as the name implies, is the technical planning necessary to ensure the efficient processing of a particular commodity. As such, it represents a very wide term, covering as it does functions in a great many industrial and commercial activities other than the purely manufacturing one, which is the concern of this book. Even considering the term when reduced to this specialised field, it will be seen as still wide in application, embracing everything from a simple capstan lathe process sheet to a complete factory layout.

The approach to process planning is never identical between one manufacturer and another. The varying conditions occasioned by the type of product produced and the respective quantities involved are the chief reasons for the recognizable differences but purely market conditions are a serious problem also, particularly at the present time, and the availability of machine tools, materials and suitable labour will often influence planning.

In the pages that follow an attempt has been made to describe the technique of process planning and the responsibilities of those engaged upon it, and, in so doing, to cover as wide a field as possible. Reference has been made to the interrelation of the planning function with those of other technicians where this has been appropriate, particularly the jig and tool draughtsman, the time study engineer and the estimator.

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CHAPTER I.

THE APPROACH TO PROCESS PLANNING.

To the casual observer metal working industries might all appear to be performing in a more or less similar manner. There is the usual tense activity of the machine shop, the noise of the press room, the heat of the foundry and the bustle of internal transport.

The initiated, however, will demonstrate that whilst there are several principles common to all manufactures, there are also some very important basic dissimilarities.

Types of Manufacture.

The methods of production used in all metal working industries fall readily into three distinct types usually known as "job", "batch" or "mass" production. This is in direct contrast to methods adopted in some other industries such as steel, glass, petroleum, etc., where production is of a continuous nature demanding specialised technique peculiar to the particular industry under review.

The experienced process planning engineer will be well versed in these proven manufacturing techniques. He will appreciate that the variation between job, batch and mass methods of production lies in the dissimilar treatments demanded in producing a given product in different quantities and at different rates of output.

A plant engaged in producing individual components or complete assemblies, one at a time, to special order, would be laid out for "job" production ; a concern specialising in the production of lots in quantities of, say, a few hundred at any one time would be planned for batch production whilst a factory turning out quantities running into several thousands would use the mass method of production.

Most works are engaged exclusively in one or other of these three types but many are operating a combination of two or perhaps all three. The manufacture of radios, cycles, typewriters, automobiles, etc., is an obvious example where plants are engaged solely in mass production. The electrical industry offers an example where all three methods may be operated within the same plant and under the technical supervision of the same process planning department.

Consider the manufacture of electric motors. The smaller sizes are required in large numbers for assembly in vacuum cleaners, washing machines, refrigerators, etc. The demand is heavy and

only the mass production method would be capable of meeting it. Concurrently with this activity the same manufacturer may be engaged on considerably smaller quantities of, say, industrial type motors, on a batch production basis and yet still be prepared to accept an order for a special purpose machine from an individual customer.

Qualifications of a Process Planner.

In view of the complexity of modern industry it may be appropriate here to review the qualifications and experience likely to be found most desirable in a successful process planning engineer.

The post demands a good knowledge of estimating and a working knowledge of jig and tool design besides practical workshop experience in as wide a field as possible. This latter should include not only as much of the characteristics of as many types, makes and sizes of machine tools and process equipment that can be conveniently absorbed, but should include also practical experience of workshop methods used in the three basic types of manufacture.

A definite standard of technical education is, of course, necessary and the Ordinary National Certificate in mechanical engineering, or success in one or two of the appropriate City and Guilds of London Institute examinations represent perhaps the minimum. It should be emphasised here, however, that technical education can be of little value without practical experience. Conversely an experienced engineer may find himself handicapped by the possession of insufficient theoretical training.

The Adoption of an Aggressive Outlook.

The general attitude of a manufacturing concern towards its production problems is usually reflected in its planning department. The productive efficiency of a whole factory may be measured against the initiative, or otherwise of the process planning engineers.

Progressive managements expect a similar progressive outlook to prevail throughout all departments, but most of all they demand its existence within the planning department.

The subject of progression in outlook is vitally important. The experienced process planner usually possesses a natural acumen for inventiveness, but if he is to become a success he must link this attribute with a definite frame of mind—a mind accustomed to considering a given process as being always below the desirable level of efficiency and to be constantly considering the most suitable methods to devise in order to remedy the deficit.

It would indeed be idle to expect a process that has been in operation over a considerable period to prove as efficient by present standards as it was when first introduced. It would also be false to imagine that having just laid down an ultra modern assembly

line constant efficiency over a number of years will necessarily be the result. The capable planning engineer, having had the satisfaction of seeing his new assembly line producing as he planned, must needs keep abreast of day-to-day mechanical innovations in order that he may keep the process up-to-date and therefore as efficient as modern conditions permit.

The Scope and Limitations of Process Planning.

Planners engaged in firms operating job, batch and mass production systems together have a decidedly more difficult task than their colleagues engaged in plants where only one production method exists. The former technicians, whilst planning the processing of components from their technical aspect, must also give due consideration to the overriding conditions occasioned by the different economics demanded when producing in job, batch and mass quantities. Planners engaged in one production method only may have occasion to consider themselves more fortunately placed. Having the opportunity to specialise in technique peculiar to one method they are able, in consequence, to restrict their thinking accordingly.

The young engineer anxious to gain experience, however, may well benefit by not specialising at an early age. By so doing he will then be qualified by experience to join firms engaged in any of the production methods. (Older technicians, while appreciating the wide scope of interest and activity at their disposal, may, nevertheless, prefer to specialise in a narrower field, believing that by so doing, they will be able to more fully justify their position).

Another important aspect is the extent to which planning methods must be specialised, in order to meet the particular manufacturing requirements of any given type of end product. Many industries manufacturing such diverse commodities as radios and lawn-mowers, kitchen ware and aeroplanes, musical instruments and automobiles call for a certain degree of specialisation of method in their production simply by virtue of the product produced.

No planner can expect to cover each and every industry. The vast knowledge and experience entailed would be beyond the capacity of any normal individual. Such a wide experience is neither necessary nor expected in practice. The products of many firms do not, by their very nature, call for a diverse machining programme. The cheap alarum clock industry is cited as an example. Here considerable press tool and some small automatic work is involved, used in conjunction with good assembly methods. These processes, however, are the only major ones of any significance. A planning engineer engaged in this work would obviously not need an extensive knowledge of large and varied machining methods

nor would a planner in the marine engine industry need any great knowledge of presswork.

The science of production engineering is a complex one and because of this it is desirable that some form of specialisation should be made on the part of the planner. It will be left to the individual to make the choice for himself.

Planners' Knowledge of Works Equipment.

It may seem almost too obvious to mention that a process planner should have an intimate knowledge of the plant within his factory.

To obtain knowledge however of a reliable character, sufficient to ensure the practicability and efficiency of any operation schedule that may be based upon it, often entails considerable effort and painstaking care. The information, to be of any value, must obviously be authentic and preferably obtained at first hand.

Office files, plant layout drawings, work station charts and so on will yield a deal of information and will prove of great value during the course of normal day-to-day duties, always provided they are kept up-to-date by means of a suitable system. The record files will give lists of accessories where these were supplied with a particular machine and also the date of the installation of that machine. What will not be available, however, are such items as the amount of wear present in slideways and bearings, etc., due to extended use, or information as to which of the accessories originally supplied with the machine is now broken but repairable or lost altogether. When dealing with machine tools that have seen much service precise information as to their condition may well decide the permissible speeds and feeds to use for a particular job or whether or not that job should be put on a certain machine at all.

Some operators in a batch production factory or jobbing shop (it does not usually arise in mass production) occasionally form a definite dislike for a particular machine and will avoid it whenever possible. In such circumstances the skilful planner will visit the workshops in person and by tact and judicious psychology endeavour to regain the operator's confidence in the machine. Should this prove impossible there will be in all probability a sound reason for the resistance and the machine in question should be thoroughly investigated and either suitably modified or a written report made to management with a view to the machine being replaced by other and more modern equipment.

Estimating.

In the engineering industries estimating is recognised as the accurate analysis and forecasting of process and handling times,

Estimating is of prime importance to the process planning engineer for without a knowledge of the principles involved together with a careful application of them, efficient planning is impossible. Estimating forms the very basis of all sound planning.

Planning any process calls for much detailed work. There are usually several ways of doing any one job. The planner's task is to decide which method to adopt in order to gain maximum efficiency. The choice should not be based upon guesswork, "experience" or upon the method by which the job was done previously. It is impossible to state with authority that a given job should be put on an automatic lathe in preference to a capstan, for instance, unless, with the quantity known, accurate estimates are first made of the corresponding setting times, floor to floor times, relative tool costs, etc., of the two machines and the figures thus obtained set against each other for comparison. In some cases the plotting of graphs is helpful in arriving at a decision. Along with these considerations handling time must be taken into account. The time consumed by handling together with the time required for machine manipulation is often far greater than actual cutting time and these considerations may in some cases override all others and hence dictate the planning sequence.

Most firms engaged in batch production use some form of piece work payment to their operators. In these concerns, the planner's original time estimates are used for the initial setting of piece-work prices. It is only when the job is underway that the opportunity arises for the time study department to make a physical time check. The rate fixer is equipped with a stop watch and has the advantage of being able to see operator, machine and jig actually performing on the shop floor. The planner has no such aids to accuracy but nevertheless should still be in a position to confidently query rate fixers' times if these are considerably in excess of his estimate. Only by such means can inefficiences be detected. It is unfair to expect shop supervision to perform this function. When the time for a job is in excess of the estimate there will obviously be one or more reasons for the discrepancy and these should be sought after and rectified. A few of the many faults likely to be met are : a badly designed jig or fixture, unsuitable or poor quality material, inefficient tooling, unsuitable operator or the process not being performed as planned. These troubles are admittedly beyond the immediate control of the process planner, but the salient feature is that having thus brought the trouble to light it is ready for rectification by the appropriate authority.

The planner's operation sheets, then, should be capable of indicating the potential output of any given component and where taken collectively the potential output of the entire factory.

In smaller firms unable to justify a separate estimating department, the planner's estimate not only supplies management with

day-to-day information for shop loading purposes, etc., but also, constitutes the basis from which calculations for quotations are made for tendering customers' enquiries.

Similar information is valuable also in batch production undertakings as an assurance that every department within the concern is operating at full capacity.

Jig and Tool Design.

The process planner should be familiar with the general principles of jig and tool design and, if his position warrants it, of press tool design also.

In many firms a planning engineer is upgraded from the tool design office. This system has much to recommend it for the average tool designer gains a fair knowledge of planning procedure during the course of his normal duties and a planning engineer must be able to visualise and estimate loading times for an undesigned jig or fixture where it merely exists as a number on an operation sheet. The system is carried to its ultimate by a few firms in this country and America where the planner is given authority, over the chief jig and tool draughtsman, to sanction a tool design before its release for manufacture in the tool room.

Jigs and fixtures are required in some form or another in every type of engineering production from the smallest jobbing shop to the largest "industrial empire." For reasons of cost, jigs are avoided wherever possible in jobbing shops and those that are made are often the result of the initiative of individual workmen and are not specially designed for the purpose.

At the other end of the scale—the mass production field—first cost is not of prime importance. Importance is attached to the speed of loading and unloading together with simple clamping arrangements to minimise fatigue. Ample strength is necessary to ensure constant trouble-free repetitive production for upwards of five years or more. All jigs and fixtures should be thoroughly foolproofed as an assurance against the vagaries of unskilled labour. Sometimes the design of a fixture for this type of production may develop into a special purpose machine. If it should, the process planner must be prepared to give the tool designer a fairly free hand for in some circumstances the planning sequence may need to be considerably modified before a workable design is obtained. With the recent reintroduction of automatic transfer machines and automation generally the process planner and tool designer are working together in a manner closer than at any previous period.

By far the largest field in jig and tool design, however, is the tooling of batch production factories. Here thousands of relatively small and fairly simple jigs and fixtures are required. First cost is important and many of the larger firms maintain a stock of standard jig parts, either of their own manufacture or obtained

from an outside supplier. It is usual for the process planner to endeavour to make one jig or fixture serve for several components of a like nature, it merely being necessary to change over a location spigot or drill bush, etc., to effect the necessary conversion. In the aircraft industry many components are handed, *i.e.*, one component is right hand and the other is left hand but otherwise similar. It is often possible under these circumstances to make one jig serve for both components.

Press tools, except the multi-stage follow-on types, are broadly similar in design no matter what the quantities to be produced may be. Most firms now use pillar die sets for the general run of small and medium pierce and blank tools. These die sets, made by specialist suppliers, considerably reduce setting time in the press shop. Also since punch and die are always in alignment punch life is considerably increased and a better quality blank produced.

The deep drawing of cups, motor body pressings, etc., demands the services of a specialist and will not be dealt with here. The process planner will need to familiarize himself however with the simple types of pierce and blank tools since he will have to determine the appropriate blank size for a given component and hence the width of the strip. These points are dealt with more fully in a later chapter.

CHAPTER II.

SIMPLE COMPONENT PLANNING.

It has already been stated in the preceding chapter that the object of process planning is to arrive directly at the most economical method of production.

It sometimes occurs, however, that the initial machining on a batch or job lot must be routed through the workshops with as little loss of time as possible. In such an emergency there may not be the opportunity for the planning department to formulate its ideal operational procedure based upon scientific principles and the initial task of the process planning engineer will be rendered a simple one. It will be necessary merely to tabulate, in sequence, any suitable series of machining operations that will produce the desired component. No estimating is required, consequently the piece parts will be probably unduly expensive and nobody in the works from the management downwards will have an accurate idea of what the work is costing or what it would cost if produced in accordance with an efficiently planned process layout.

A Simple Operation Schedule.

Fig. 1 shows a simple component for which an operational sequence is required. The material, it will be noted, is $1\frac{5}{8}$ in. square mild steel and there is a turned portion at one end and a milled and drilled portion at the other.

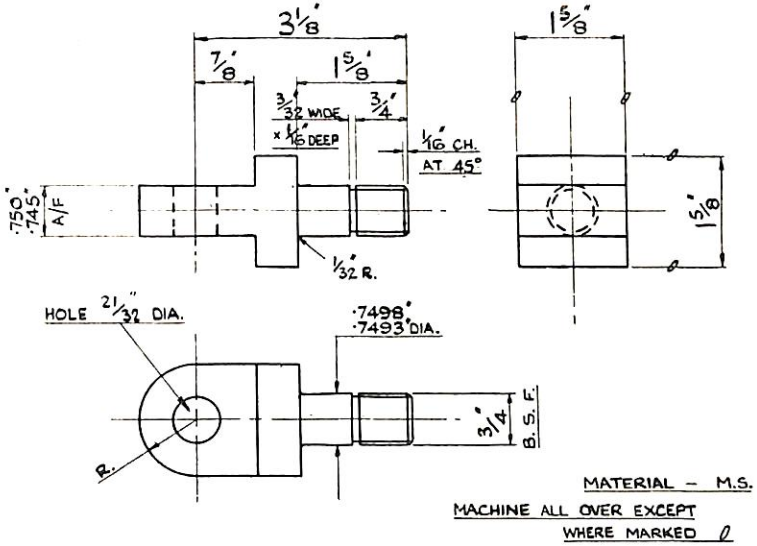


Fig. 1.

Before writing anything down the planner should study the drawing closely. As a first operation it would appear possible to do either the milling at the one end or the turning at the other, the choice depending, to some extent, upon the plant available. Assuming a capstan or turret lathe is used, or an automatic machine if quantities required are large, it may prove desirable to machine the turned end of the component first using material in the form of $1\frac{5}{8}$ in. square bar. Should, however, a suitable capstan lathe not be available, an alternative method will have to be used. The material could be cut up into short lengths with a cold saw and the individual pieces chucked in a smaller capstan. If the number of components required is very small the sawn off pieces might even be centred at both ends and turned on an engine lathe. In all cases the planner would call for screwing tackle appropriate to the particular machine chosen.

The milling will be accomplished in two operations at least, since it involves gashing to form the $\frac{\cdot 750}{\cdot 745}$ in. dimension and then setting up again or transferring to another machine to form the $\frac{13}{16}$ in. radius. If the $\frac{\cdot 750}{\cdot 745}$ in. dimension is generated first an advantage will be gained in that less material will need to be removed by the $\frac{13}{16}$ in. radius form cutter. As with the turning operation consideration must be given to the quantity of components required and the types of milling machines available. Where only a small quantity is required and the range of milling cutters held in store is limited, the job may be marked out and the $\frac{\cdot 750}{\cdot 745}$ in. dimension gashed one side at a time with a normal side and face cutter, either in a horizontal or a vertical miller. Should a radius cutter not be available it may be permissible in order to gain the desired form to remove the excess material by milling two substantial chamfers at 45° and then hand filing to the finished contour, or routing with an end mill.

In a well equipped batch production factory the milling operation would be performed quite differently. A fixture would be called for complete with setting blocks and cutter gang assembly pre-set to the required limits. Two or three components would be loaded in the fixture at one time and a further milling fixture, together with a suitably radiused milling cutter, would be used for the second operation.

When the component is considered in mass production quantities

the $\frac{\cdot 750}{\cdot 745}$ in. dimension may be milled using two fixtures, similar to that just indicated for the batch method. By mounting one at either end of the machine table, the operator can unload and load one fixture whilst the components contained in the other fixture are under cut. An arrangement of this type can be expected to save 65% and upwards in machining time. For production in really big quantities a special purpose machine might be considered.

Refer now to the $\frac{13}{16}$ in. radius. Special form milling cutters are not desirable in mass production. They are expensive in first cost, may lose their form after a few regrinds and require to be run at a relatively slow rate of feed. Here, then, is an instance where it may prove profitable to approach the designs department with a view to a concession being granted to facilitate production. This radius is probably not important for the correct functioning of the component and it might be suggested that the raw material be supplied as a forging and the $1\frac{5}{8}$ in. square and the $\frac{13}{16}$ in. radius be left as forged, the advantages being that the depth of cut around the $\frac{\cdot 750}{\cdot 745}$ in. dimension would be considerably less and, of course, the $\frac{13}{16}$ in. radius milling operation would be excluded altogether. Should the machining of the radius be deemed necessary but the $1\frac{5}{8}$ in. square dimension be relatively unimportant, a request might similarly be made that the component be machined from $1\frac{5}{8}$ in. dia. round stock in place of square. Economies would accrue if this latter suggestion were adopted since round material would be cheaper in first cost and also normal collets could be used in preference to the square type. Square collets are not usually considered to be general machine shop equipment, especially in the smaller shops, and in consequence these may have to be purchased specially for the job.

Drilling is the final operation. The hole would probably be marked out and drilled without a jig in a jobbing shop, but for batch and mass production quantities jigs would be required, varying in elaboration in almost direct proportion to the quantities of components involved. Fig. 2 shows a typical operation sheet which includes a suggested layout for machining the component just described. Note the method of numbering the operations. This facilitates any subsequent additions that may be found necessary due to product design change, etc.

Tool Layouts and Process Sheets.

In order to ensure that identical processing conditions shall prevail every time a batch order is placed on the shop, some planning departments issue tool layouts and process sheets,

OPERATION

Component Name—ANCHOR BOLT *Material*—Mild Steel

Planned by *Checked by*

Op. No.	Description of Operation	Dept.	Machine Name and Number	Process Drg. No.
1	Draw $1\frac{5}{8}''$ sq. bar from stores			
5	Hold in $1\frac{5}{8}''$ sq. collet Finish turn $\frac{\cdot 7498''}{\cdot 7493''}$ dia. $\times$ $1\frac{1}{32}''$ long in two operations Face shoulder face forming $\frac{1}{32}''$ R. Roller face end to give $1\frac{5}{8}''$ dimension Form $\frac{1}{16}''$ chamfer at 45° Form undercut to drawing Screw $\frac{3}{4}''$ B.S.F. $\times$ $\frac{3}{4}''$ long to drawing Part off $4\frac{1}{16}''$ long and break down bar	Capstans	Ward No. 7 with $2\frac{1}{2}''$ dia. Spindle	550
10	Hold on $1\frac{5}{8}''$ sq. dimension Straddle mill tongue $\frac{\cdot 750''}{\cdot 745''}$ wide $\times$ $1\frac{13}{16}''$ deep to give $\frac{5}{8}''$ wide shoulder	Milling	Cincinnati 1-18	551
15	Hold on $1\frac{5}{8}''$ sq. dimension Mill $\frac{1}{16}''$ radius, blend to give $3\frac{15}{16}''$ overall length	Milling	Brown & Sharpe	552
20	Burr	Fettling	Bench	
25	Drill $\frac{21}{32}''$ diameter hole	Drills	Asquith S. Spindle Sensitive	553
30	Inspect	Inspection	Bench	

SHEET

Part No. 1001

Tool Layout No.	Jig	Fixture	Tools	Standard Tools	Time (Mins.) D.W.	Time (Mins.) P.W.
325			2 off Roller box tool bits T.C. $\frac{1}{32}$″ R. facing tool T.C. Undercut form tool T.C. face and ch. tool bit H.S.S. Parting tool H.S.S.	$1\frac{5}{8}$″ sq. collet Stock stop 2 off Roller boxes Roller ending steady R. tool post F. tool post Coventry die head		4·00
326		Fixture loading 3 at a time Spacer $\frac{\cdot 748''}{\cdot 747''}$	2 off S. and F. cutters 6″ × $\frac{5}{8}$″ × $1\frac{1}{4}$″	Arbor Spacing collars as required		·96
327		Fixture	Radius Cutter	Arbor Spacing collars as required		1·34
				File Gloves	·25	
			$\frac{21}{32}$″ dia. drill	Jacobs chuck		·30
				$\frac{\cdot 750''}{\cdot 745''}$ snap gauge undercut gauge $\frac{21}{32}$″ dia. plug gauge $\frac{3}{4}$″ B.S.F. screw caliper gauge		

Fig. 2.

A tool layout, as the name implies, is a drawing showing the set-up of a machine for a particular operation and lists standard and special tools and any other jigs or fixtures that may be required for that operation.

A process sheet is a drawing showing the component in its machined state, up to and including the operation to which the process sheet refers. The machining in this latter operation is lined in heavily on the drawing and dimensioned to indicate the precise nature of the operation. Fig. 3 shows a series of tool layout sheets for the component in Fig. 1 and Fig. 4, a series of process sheets for the same component. Should it be decided that the material be supplied as a forging a further process drawing as shown in Fig. 5 might be issued. If $1\frac{5}{8}$ in. dia. round stock is used the drawings in Figs. 3 and 4 would need appropriate modification.

Machine Manipulation Times.

Having introduced the method of process planning by way of illustrating a simple operation sheet and tool layout, machine manipulation time will now be considered in some detail. It has already been shown in Chapter I that efficient process planning is impossible without accurately estimated floor to floor times being available. It is necessary then, that the process planner be able to establish such data for himself should this information not already be available.

Every operation in repetitive manufacture consists of a complete cycle. A component is picked up, worked upon and put down again. In appreciation of this, the rate fixer always times an operation upon a cycle basis ; taking as his datum some point of demarcation such as a distinctive click or pause, etc., which occurs regularly once during each cycle.

From the process planner's point of view, however, every cycle may be considered as divided into a number of what may be termed constituents, these being in addition to the actual cutting operations themselves. For instance, a turning operation may be divided into handling component, machine manipulation (bringing tools up to the work) and cutting. If required the operation may be further sub-divided into picking up component, loading into chuck, manipulating machine, cutting, unloading from chuck, gauging work and finally setting component down again.

A little reflection will reveal that there must exist in any repetitive process several other small but necessary operations, some being done once a day or only occasionally. Such operations as grinding and replacing tools and cleaning down machine, overcoming adverse conditions beyond the operator's control such as dealing with hard spots in occasional castings or waiting unduly for services such as transport, tool replacements, etc. These

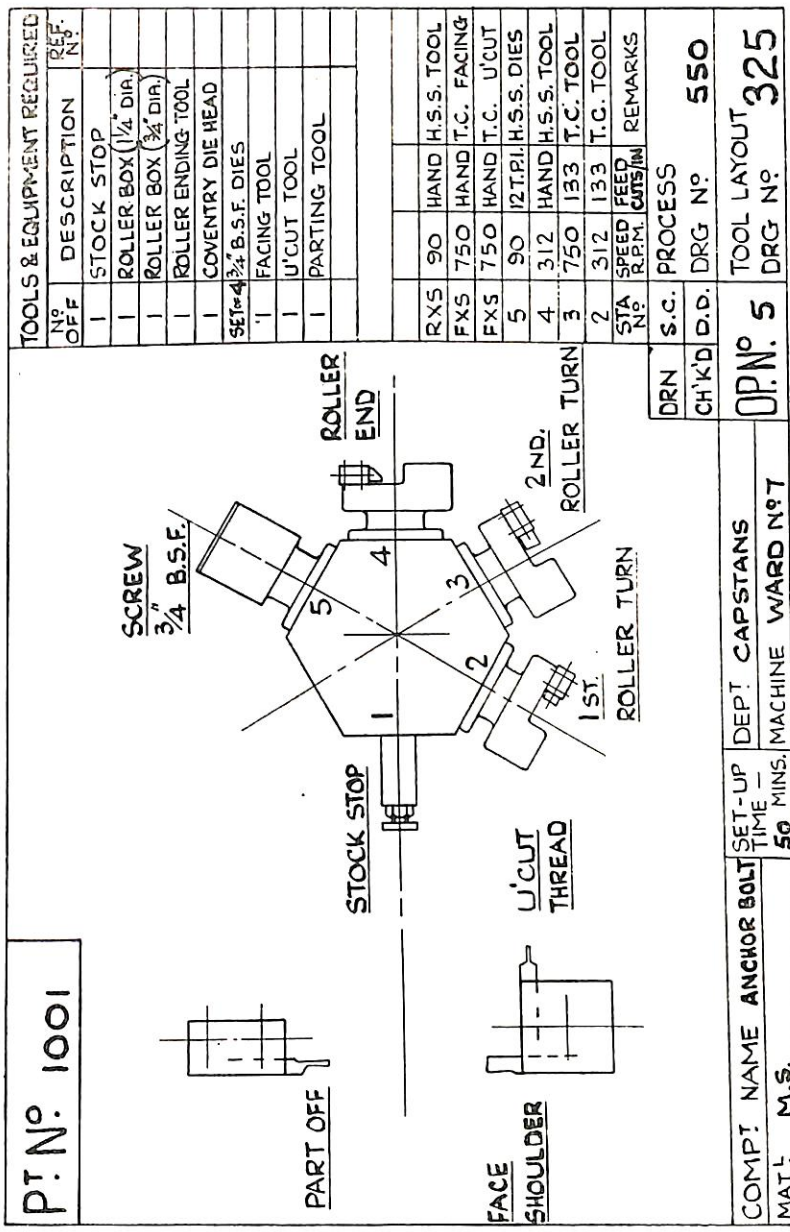

PT. No. 1001
TOOLS & EQUIPMENT REQUIRED
No OFF
DESCRIPTION
REF. No
1 STOCK STOP
1 ROLLER BOX (1¼" DIA.)
1 ROLLER BOX (¾" DIA.)
1 ROLLER ENDING TOOL
1 COVENTRY DIE HEAD
SET of 4 ¾" B.S.F. DIES
1 FACING TOOL
1 U'CUT TOOL
1 PARTING TOOL
SCREW ¾" B.S.F.
ROLLER END
STOCK STOP
2ND. ROLLER TURN
1ST. ROLLER TURN
PART OFF
FACE SHOULDER
U'CUT THREAD
1
2
3
4
5
RXS 90 HAND H.S.S. TOOL
FXS 750 HAND T.C. FACING
FXS 750 HAND T.C. U'CUT
5 90 12T.P.I. H.S.S. DIES
4 312 HAND H.S.S. TOOL
3 750 133 T.C. TOOL
2 312 133 T.C. TOOL
STA No. SPEED R.P.M. FEED CUTS/IN REMARKS
DRN S.C. PROCESS
CH'K'D D.D. DRG No. 550
COMPT NAME ANCHOR BOLT
MAT'L M.S.
SET-UP TIME — 50 MINS.
DEPT CAPSTANS
MACHINE WARD No 7
OP. No. 5
TOOL LAYOUT
DRG No. 325

Fig. 3a.

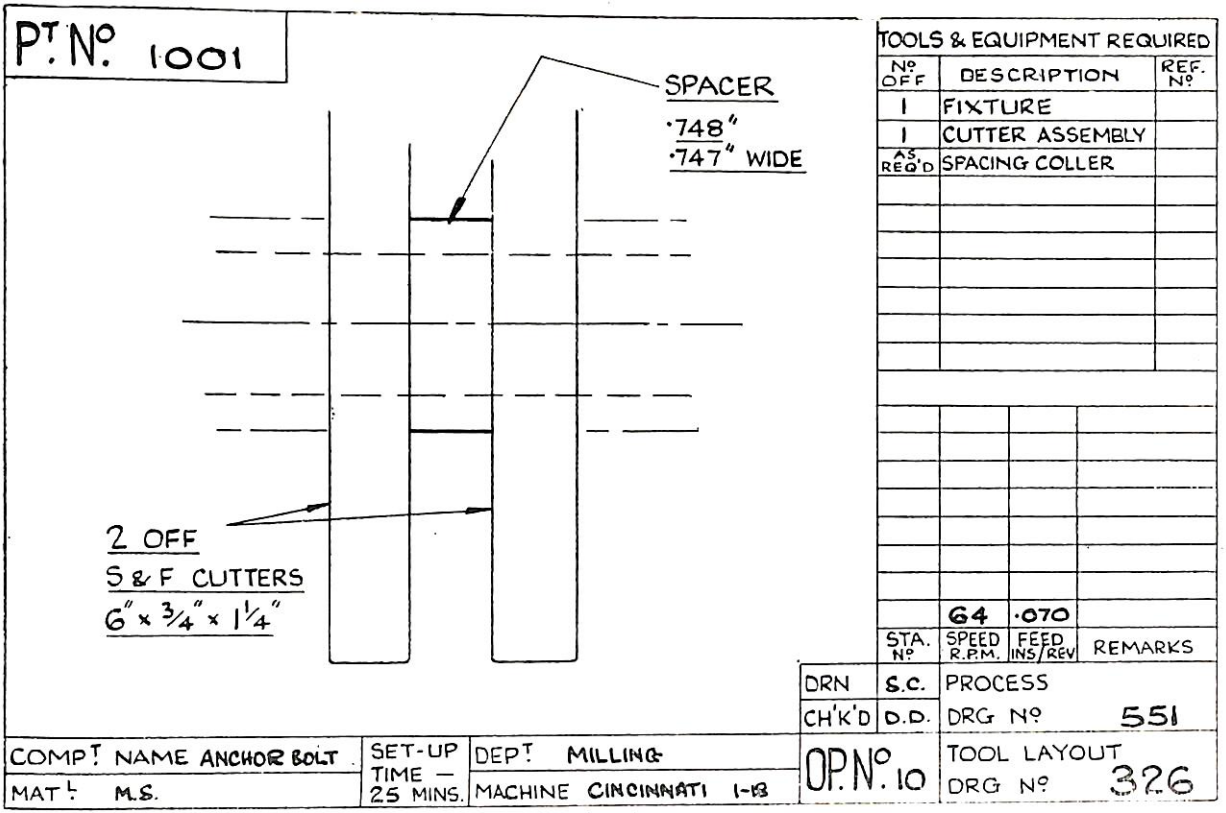
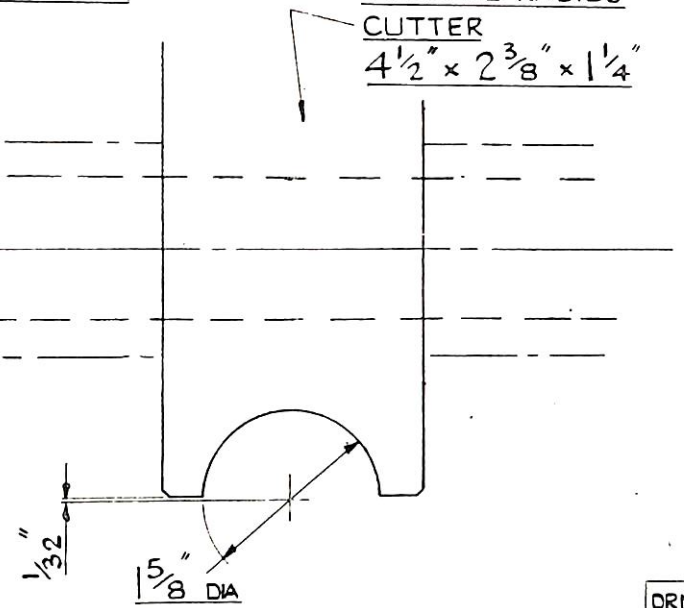

Pt. No. 1001
SPACER
·748"
·747" WIDE
2 OFF
S & F CUTTERS
6" x 3/4" x 1 1/4"
TOOLS & EQUIPMENT REQUIRED
No. OFF
DESCRIPTION
REF. No.
1 FIXTURE
1 CUTTER ASSEMBLY
AS REQ'D SPACING COLLER
64 ·070
STA. No.
SPEED R.P.M.
FEED INS/REV
REMARKS
DRN S.C.
CH'K'D D.D.
PROCESS
DRG No 551
COMPT NAME ANCHOR BOLT
MAT'L M.S.
SET-UP TIME — 25 MINS.
DEPT MILLING
MACHINE CINCINNATI 1-13
OP. No. 10
TOOL LAYOUT
DRG No 326

Fig. 3b.

Pt. No. 1001



TOOLS & EQUIPMENT REQUIRED		
No OFF	DESCRIPTION	REF No
1	FIXTURE	
1	RADIUS CUTTER	
AS REQ'D	SPACING COLLER	

STA. No	SPEED R.P.M.	FEED INS/REV	REMARKS
	86	030	

DRN	S.C.	PROCESS	
CH'K'D	D.D.	DRG No	552
COMPT NAME ANCHOR BOLT	SET-UP TIME — 20 MINS	DEPT MILLING	OP. No. 15
MATL M.S.		MACHINE B & S	TOOL LAYOUT DRG No 327

Fig. 3c.

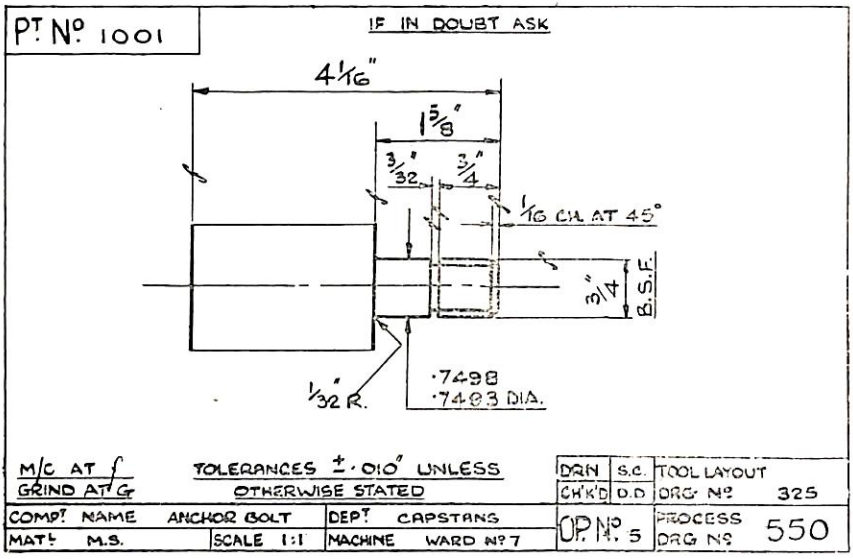

Pt. No. 1001
IF IN DOUBT ASK
4 1/16"
1 5/8"
3/32"
3/4"
1/16 CHAMFER AT 45°
3/4" B.S.F.
1/32" R.
·7498
·7493 DIA.
M/C AT f
GRIND AT G
TOLERANCES ± ·010" UNLESS OTHERWISE STATED
DRN
CH'K'D
S.C.
D.D
TOOL LAYOUT
DRG No 325
COMPT NAME ANCHOR BOLT
DEPT CAPSTANS
MATL M.S.
SCALE 1:1
MACHINE WARD No 7
OP. No. 5
PROCESS
DRG No 550

Fig. 4a.

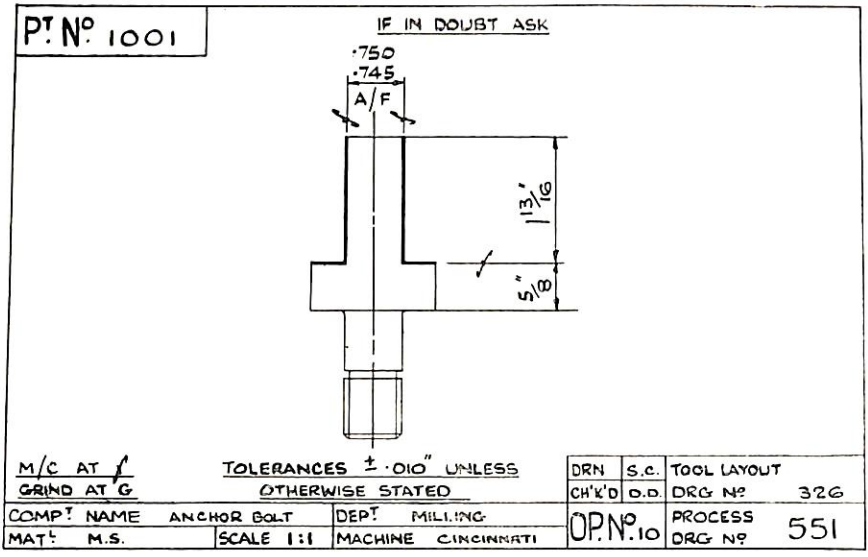

Pt. No. 1001
IF IN DOUBT ASK
·750
·745
A/F
1 3/16"
5/16"
M/C AT f
GRIND AT G
TOLERANCES ± ·010" UNLESS OTHERWISE STATED
DRN
CH'K'D
S.C.
D.D
TOOL LAYOUT
DRG No 326
COMPT NAME ANCHOR BOLT
DEPT MILLING
MATL M.S.
SCALE 1:1
MACHINE CINCINNATI
OP. No. 10
PROCESS
DRG No 551

Fig. 4b.

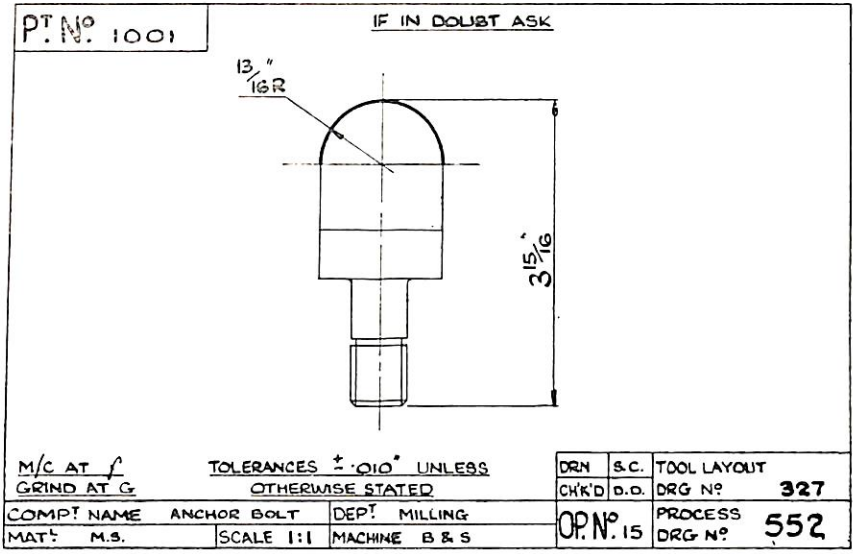


Fig. 4c.

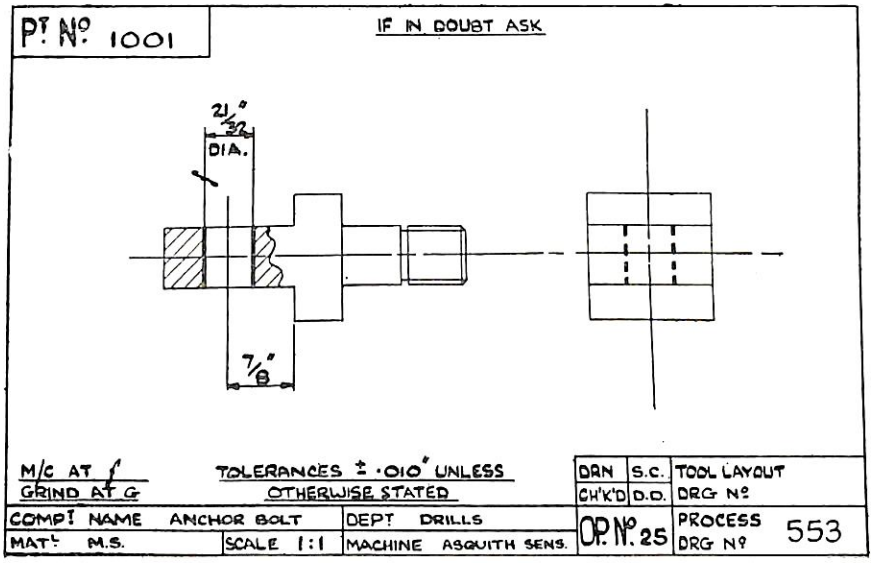


Fig. 4d.

D

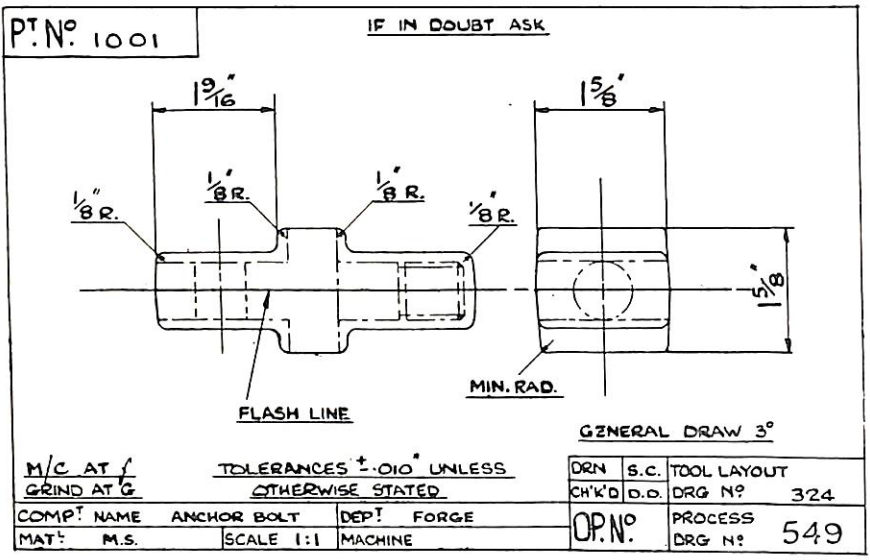


Fig. 5.

operations cannot be reckoned in the cycle time but nevertheless are important and must be taken into account.

It is possible, of course, to make a time study of the constituents of any operation and many of the more usual are listed in tables to be found in the appendix. The other considerations just mentioned, however, which occur only occasionally and consequently are not included in the cycle time, are not timeable by any practical method and are usually lumped together and allowed for by adding a percentage to the estimated cycle time. This percentage is usually known as the contingency allowance. Personal convenience must also be considered and when not included in the contingency allowance must be similarly added as a percentage of operation time. The figure is normally about 3% for men and 5% for women.

Thus every operation is composed of cutting time, constituent time plus personal and contingency percentages. The latter varies for different operations, different operators and different types of work. $12\frac{1}{2}\%$ is a fair average to apply to medium work, $7\frac{1}{2}\%$ for light work requiring little concentration and anything up to 30% or more for very heavy work to fine limits. These figures assume no wait due to inefficient tool stores, bad lighting over machines, inaccuracies contained in the component due to foundry errors or other factors beyond the operator's control. $12\frac{1}{2}\%$ represents the average allowance to apply to any operation but

more accurate figures will be quoted later when dealing with specific machining processes.

Exceptional operators will vary at least 30% in manipulative speed above or below the average, but in the main, the observed time as taken by the rate fixer should substantially agree with the estimated time of the planner. Constituent times as given in the tables already referred to, apply to operations in full production, *i.e.*, when the operators have learned the motions and have gained confidence both in themselves and the machines. When a new job is put on the shop these times may need to be increased by 50% or more for the first week, 25% for the second and 10% for the third. Where work is required to be held to exceptionally close limits the percentage may need to be almost doubled. Very simple processes such as sensitive drilling and fly press work, etc., reach their fastest speed within a week and only about 30% should be added during this initial period. There is justification for a still further increase in times where quantities to be produced are small, *e.g.*, a batch of medium sized components comprising about 20 - 50 off.

It will be seen from the foregoing that there is an appreciable number of possible variables to be taken into account when estimating a given job. Indeed the range of these variables may seem so wide as to constitute a formidable obstacle to a reliable estimate being obtainable. In practice, however, planning departments must specialise to a certain extent on the production peculiarities of the type of product with which they are usually concerned. Hence only a restricted set of circumstances is likely to enter into contingency estimations. Nevertheless contingency percentages must be accurate. It is useless for the rate fixer to attempt to observe an operation during the "learning" period on a new job, and the initial piece-work price, therefore, is usually based upon the estimated floor to floor time as given by the planner.

Speeds and Feeds.

For the purposes of calculating the highest permissible speeds and feeds to use for an operation, it is usually assumed that modern machines in good condition are used and that these are capable of withstanding the loads imposed by such optimum speeds without chatter or vibration or loss of component accuracy, also that the design of the jig or fixture is a sound one, robust enough to absorb machining vibrations and, of course, in good condition.

If these requirements are maintained, cutting speed will be governed principally by the hardness of the metal to be machined and also the material with which the cutting tool is made, be it carbon steel, high speed steel, Stellite, tungsten carbide or one of the many variants of these basic types. The shape of the tool

and its heat treatment must be taken into consideration together with the feed and the depth of cut, the coolant used, if any, and the power of the machine. Instances will arise where permissible speeds will have to be reduced because the design of the component being machined or its material composition, renders it insufficiently rigid to withstand the cutting action. Reference to the designs department may lead to improved machining conditions being obtained by the introduction of suitable design modifications in the light of this experience. When cutting brass, aluminium and other light alloys the optimum cutting speed may be so high as to be unobtainable on the machine and the highest available speed has to be used. This applies especially to the older type machines.

Cutting speed is further influenced by the length of time expected between regrinds. It is usually considered uneconomical to run a turning tool longer than $1\frac{1}{2}$ hours before regrinding or a drill longer than $\frac{1}{2}$ hour. The exceptions are to be found in multi tool turning, automatic lathes, multi drilling heads, etc., where speeds are kept low in order that tool life may extend to one complete shift of eight hours at least before attention becomes necessary.

Obviously any published data on speeds and feeds, therefore, can be approximate only, much necessarily being left to the experience of the process planner to decide individual cases as they are encountered.

Suggested speeds and feeds, therefore, are not given in this book since tables are to be found in any standard reference book on workshop practice. When required, further information of a more detailed nature is always freely obtainable from the actual machine tool manufacturers themselves and from the manufacturers of small tools such as twist drills, milling cutters, etc.

CHAPTER III.

MACHINING PROCESSES.

It is proposed in this chapter and the next to study briefly the major machining processes from the point of view of the process planner. The machines themselves will not be described purely from a mechanical standpoint but rather a survey will be made of the conditions that influence their economic operation.

It is the process planner's responsibility to plan processes efficiently and this is only possible where a thorough knowledge is held of the economic possibilities of the various types of machine tools when operated under widely varying conditions.

Drilling, Reaming and Tapping.

Consider a typical drilling operation. After deciding upon the speed and feed at which the drill is to operate, it is possible to evaluate the cutting time for a hole of known depth. When drilling deep holes, *i.e.*, holes whose depth is equal to or greater than three times the diameter, an allowance might be made for the drill to be withdrawn during the cut to facilitate the clearance of swarf.

For most purposes reamers may be run at half drilling speed size for size and twice the rate of feed. Mild steel is often reamed at drilling speed. The successful use of a high reaming speed depends upon the drilling of a straight and accurately sized hole and the reamer removing $\frac{1}{64}$ in. on diameter on holes up to about $\frac{7}{16}$ in. diameter and $\frac{1}{32}$ in. on diameter on holes above this size. Most drills cut large and if accuracy in this respect is required the use of a three flute drill for the larger sizes might be considered. This latter will cut more accurately both as regards diameter and straightness. Combination drill and reamers are often used in large quantity production, although they cannot, of course, be used for finishing blind holes.

Spot facing, counterboring and deep countersinking may be produced at the corresponding drilling speeds but feeds should be halved. The cutting time lost is negligible since most spot facing, etc., is for a very limited depth. The wear on tools is often much greater due to their having to cut through the skin of castings, fillets and other irregularities. Extra travel of about $\frac{1}{8}$ in. should be allowed to give a dwell to obtain a fine finish. The actual cutting time for light countersinking or frazing is negligible and only handling time enters into the calculations—about 1 - 3 seconds per hole.

Tapping.

Tapping operations closely resemble those of drilling and reaming as regards constituents except where the tap is lubricated occasionally by means of a piece of tallow, when about three seconds should be allowed for this extra movement.

Having decided upon the most suitable peripheral speed to use for the tap the feed, of course, will depend upon the pitch of the thread to be cut. Note the real depth that the tap enters the hole should be used in calculations not the depth of full thread which is somewhat less due to the lead on the tap.

The retreat of the tap is usually accomplished at about twice the feed-in speed, but where very soft material is being tapped care is often required to prevent stripping the thread, and in such cases the retreat speed could well be reduced to that of the feed-in speed.

Turning.

The most familiar of all the many different types of turning equipment is the common centre lathe. A table in the appendix will be found giving constituent times for this class of work. The chucking times, it will be noticed, are based upon weight but where castings, etc., are of exceptionally solid and compact design, facilitating easy handling, the times may be decreased, by careful judgment, often by as much as 30%.

Speeds and feeds for final cuts will depend upon the finish required. Speeds and feeds for roughing however may be the maximum compatible with the power of the machine. It follows, therefore, that some means of quickly evaluating H.P. requirements is advantageous.

The pressure on the cutting edge of a turning tool is given by multiplying the area of the cut by the feed per revolution. With a cut $\frac{3}{16}$ in. deep $\times$ ·020 in. feed on mild steel the load on the tool is :—

$$\frac{3}{16} \times \cdot 020 \times K = 0{\cdot}43 \text{ tons.}$$

Where K = 115 tons.

Similarly K is usually taken as 150 tons for tough steel, 80 tons for cast iron, and 44 tons for brass.

Now 0·43 tons acting through a cutting speed of say 90 feet per minute

$$= \frac{\text{load in lbs.} \times \text{distance in feet}}{550 \times \text{time in seconds}}$$

$$= \frac{\cdot 43 \times 2240 \times 90}{550 \times 60}$$

$$= 2{\cdot}6 \text{ H.P.}$$

The quantity of material removed by this cut in one minute will be,

$$= \text{cross section of cut} \times \text{length in inches}$$
$$= \cdot1875 \times \cdot020 \times 90 \times 12$$
$$= 4\cdot05 \text{ cubic ins.}$$

Hence using these figures, the power required to remove 1 cubic inch of mild steel will be :—

$$\frac{2.6}{4\cdot05}$$
$$= \cdot64 \text{ H.P.}$$

or 1 H.P. will remove about $1\frac{1}{2}$ cubic ins. per minute.

Similarly 1 H.P. can be expected to remove approximately 1 cu. in. per minute from tough steel, ·75 cu. in. from 50 ton tensile steel, 2 cu. ins. from cast iron and 4 cu. ins. from brass. When drilling is to be done in the centre lathe horse-power requirements may be estimated by doubling these values given for turning. (Per cubic inch of material removed).

When computing horse-power requirements it will be realised that from the point of view of economy it is always desirable to take the minimum number of cuts, usually a heavy roughing cut followed by a lighter semi-finish or finishing cut. It follows, therefore, that the power absorbed by the roughing cut should be the figure used in horse-power calculations.

In mass production semi-automatic multi-tool centre lathes are used. Fig. 6 shows a typical component mounted between centres and also indicated is the tooling set up. Speeds and feeds

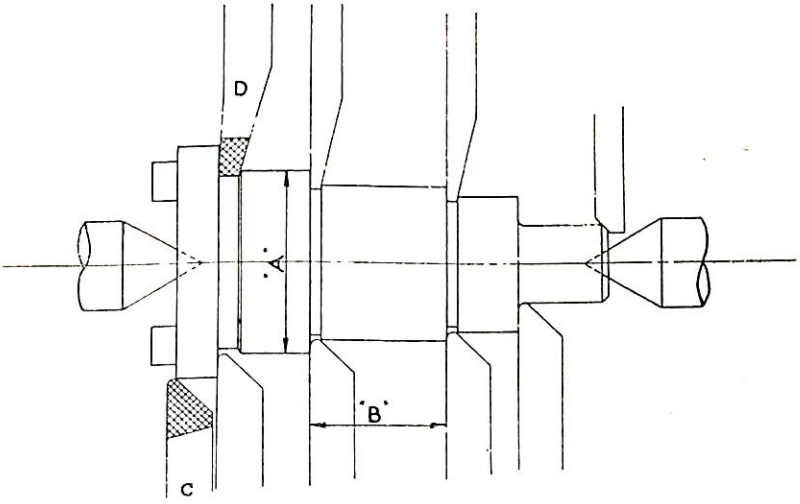


Fig. 6.

are less than normal centre lathe practice in order to prevent frequent regrinds of the tools becoming necessary. Also, in limited circumstances, it will be found that more rapid cutting will absorb too much power and either stall the machine or spring the work.

The total cutting time for the operation is the time to cut the longest shoulder, in this case length B. The spindle speed is selected to suit the largest diameter. This latter requirement may be modified in some cases by using tungsten carbide tipped tools for cutting the larger diameters and using high speed steel tools on the smaller dimensions. By this means a higher overall cutting speed becomes permissible. In Fig. 6, tools C and D are carbide tipped to take advantage of this fact. Whether or not further use could be made of carbide tooling in the set-up with a view to still greater increases in speed being obtained would depend upon the power of the machine and the rigidity of the component.

It is usual in such applications as this to take advantage of any holes, lugs or slots, etc., in the component by using these to obtain a positive drive, no carrier being normally used. Thus the planning sequence for such a component would call for the driving medium, whatever it may be, to be machined prior to the multi-tool turning operation.

Batch production factories make extensive use of the capstan lathe and this versatile machine is also to be found in the toolrooms and "feeder" departments of most mass producing establishments.

Table 4 gives some useful constituent times for several sizes of capstan lathe but much of the data given for centre lathes may be similarly applied to capstan work. Speeds and feeds are usually slightly less since several cuts are normally in progress at any one time.

Screwing is usually done by means of self-opening die heads needing no time allowance for screwing off except the normal turret indexing time. Occasionally button dies are used for a final cut and the reverse in this case is often about $\frac{2}{3}$ the speed of the forward motion.

Set up time depends upon the complexity of the tooling and can be anything from 20 - 60 minutes or more. A simple formula which may be used in a shop with an efficient tool service is :

$$\text{Set-up time} = 20 + (5 \times \text{no. of tools}) \text{ in mins.}$$

i.e., if there are a total of eight tools in the set-up regardless of type the time would be,

$$20 + (5 \times 8)$$
$$= 60 \text{ mins.}$$

It must be emphasised, however, that this time is allowable only where an efficient and an effective tool service is available. In shops where a haphazard system is tolerated or where no system at all exists, setting times are almost unpredictable.

Tool layout drawings are great time savers, and can be expected to cut setting time by about 25%. Setters should be encouraged where possible to retain one component from a previous batch since their work is greatly facilitated when they are able to make a rough preliminary setting from a sample component.

Automatic Lathes and Screw Machines.

Automatic lathes are available either as collet or chucking machines and almost any job that can be done on a capstan lathe can be done with similar accuracy and consistency on an automatic. The choice as to which machine to use for any particular job, *i.e.*, capstan lathe or automatic is purely a question of economics.

The automatic screw machine closely resembles the smaller wire feed capstans but it has the valuable advantage that many attachments are available for use with it making it possible to mill flats, slot bolt heads and screw the back end of turned components, etc., during the normal machining cycle.

In all automatic work, the idle movements, such as index turret, traverse cross slide, etc., are accomplished in considerably less time than similar movements on the capstan machines. Furthermore it is possible to overlap cutting operations to a greater extent than is practicable on a capstan This latter feature, amongst others, enables the automatic machine to produce a given component in a considerably shorter cycle time.

Milling.

Typical times for clamping components in either a fixture or a vice are given in Table 1. Times for actually handling the component and locating it in the fixture are similar to drill jig loading times but clamping time is greater, since milling is a considerably heavier operation than drilling, necessitating the use of more and heavier clamps. Table 1 gives times for locking various clamping devices and the process planner when estimating must visualise the fixture that he will be calling for and decide how many clamps the component will be likely to need and establish floor to floor times accordingly.

In a well equipped shop setting for the usual run of small components does not present very much difficulty. There is usually the task of moving machine vices and heavy fixtures on and off the table which is likely to cause delay where suitable lifting tackle is either not available or has to be waited for unduly.

Twenty minutes should be sufficient to set up a simple job using a fixture and one cutter. The set up time for straddle milling will be very little more where there are open limits but a further fifteen minutes should be allowed if dimensions are required to be within about ·002 in. or less. In large batch production factories

milling cutters are carried in stock by the tool store already set up on their arbors to the required tolerance which, of course, reduces setting time considerably.

As with turning, tool layout drawings and the use of a sample component for setting purposes will save appreciable time.

Setting in mass production is of no account since a job may be continuously running for several years but cutter changes are important and must be allowed for.

Apart from the consideration of the actual material being cut the power absorbed by milling depends primarily upon the type of cutter that is used. The old fashioned cylindrical cutters or "roller mills" are wasteful of power and wherever possible use is now made of the modern inserted tooth face mills. These are found to give a better finish in less time as well as being more economical in power consumption. As in turning it should be ascertained whether the power of the machine is adequate for the cut it is proposed to take. Table 6 gives approximate horse-power requirements for removing one cubic inch of material in one minute using modern positive rake cutters.

All milling operations require that the travel of the cutter be appreciably longer than the actual length of cut in the component. Fig. 7 illustrates this point. In estimating floor to floor times therefore due allowances must be made. This extra travel may be calculated by simple trigonometry but to obviate the necessity for making tedious calculations every time a milling operation is to be planned Tables 7 and 8 have been prepared for quick reference.

Where continuous milling is practised, as in mass producing automobile cylinder blocks, several fixtures are mounted on a rotary table or drum. The floor to floor time in this case is :

$$\frac{\text{Time to make 1 rev. of table or drum}}{\text{Number of components passing per rev.}}$$

Often the deciding factor is handling time since the rate of production cannot be faster than the component can be loaded and unloaded from the fixtures.

Grinding.

There are three types of grinding machines in common use together with several special purpose units. The more usual types are cylindrical (internal and external), centreless and surface. The special purpose types include crankshaft and camshaft grinders, spline and thread grinders and the usual cutting-off machines using elastic wheels. Also available, but not very common, are face grinding machines having an action similar to a horizontal milling machine but being provided with a grinding wheel on the stub arbor in place of the face mill. Plano grinders are used in heavy

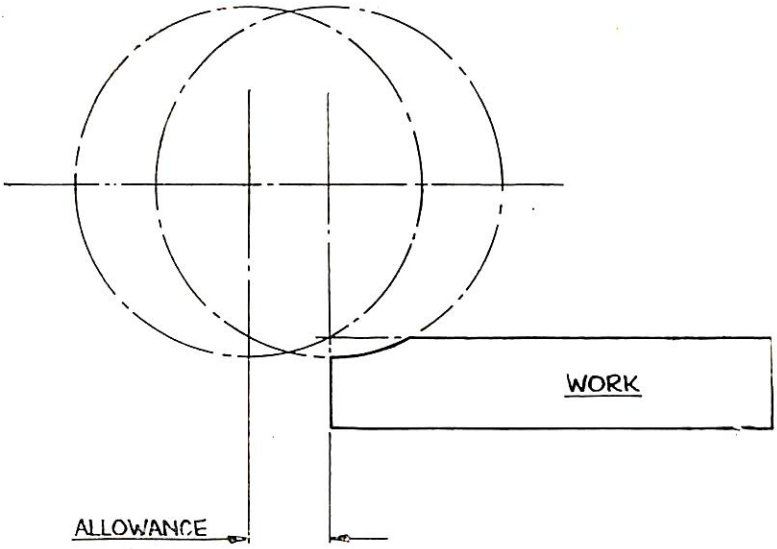


Fig. 7a.

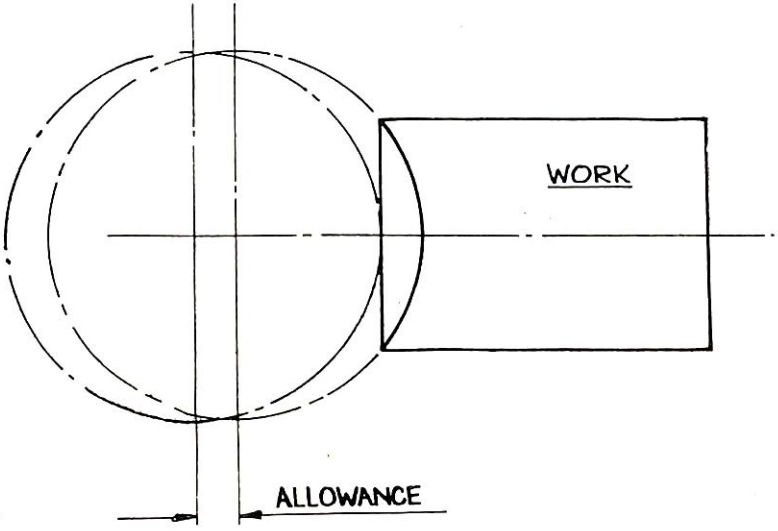


Fig. 7b.

industry and are similar to a normal planing machine but fitted with one or more grinding heads in place of the tool boxes.

Grinding speeds are considerably higher than other forms of metal cutting machining. Wheel speeds of between 4,000 and 5,000 surface feet per minute are used for surfacing, 5,000 - 6,500 s.f.m. for cylindrical grinding and between 7,000 and 16,000 s.f.m. for cutting off wheels. If the same wheel is used for roughing as is used for finishing, a reduction in the work speed of about 25% is recommended for the finishing operation.

The traverse speed, *i.e.*, the speed of the wheel, or of the work, whichever may be the case, is about $\frac{3}{4}$ of the wheel width per revolution of the work for roughing and about $\frac{1}{5}$ of the wheel width per revolution for finishing. Depth of cut per pass is often ·002—·004 in. for roughing and ·0007—·0025 in. for finishing.

A useful formula for calculating actual cutting time on the grinding machine is :

$$T = \frac{D \times L}{F \times C \times R} + (N+1)\,K$$

where

D = half the difference between original and required diameter

i.e., $\frac{D-d}{2}$

L = length of work plus overtravel.
F = feed in ins./rev. of work.
C = depth of cut in ins. per pass.
R = revs./min. of work.
N = number of passes required.
K = constant, approx. ·05 (allows for dwell at end of each pass).

The technique of centreless grinding is composed of three different and distinctive methods of operating the same machine known respectively as through-feed, in-feed and end-feed.

The through-feed system is extensively used in mass production to obtain close tolerances economically on straight cylindrical components. There is no handling time since the components are being constantly fed to the machine during the grinding process which is continuous. When used in this manner the capacity of the machine is such that it is possible to accept components of widely differing dimensions. Sizes may be anything from a fraction of an inch to 20 feet or more in length and from about ·012 in. up to about 4 inches in diameter. The stock removed per pass by this method is limited and must not be greater than about ·006 in. - ·007 in. on diameter. For finishing it may be considerably less.

In-feed centreless grinding is used for grinding components with shoulders where it is impossible to use the through feed method or where a greater amount of stock removal is required. The component to be ground is laid on the work rest. The control wheel is brought up to it and in continuing its travel pushes the work over and onto the grinding wheel. When the control wheel reaches a stop the reverse action takes place and the part is automatically ejected. A further advantage of this method is that form grinding may be accomplished by suitably shaping the grinding wheel. The process is unsuitable where components have a ground surface longer than the width of the wheels. For such cases the end-feed method is used.

End-feed centreless grinding is simply the feeding in of the component similar to through-feeding but a stop is provided for the component. As soon as the part has fed itself in up to this stop the control wheel retreats and the component is ejected.

Surface grinding machines are of two main types, reciprocating table as in milling and rotary table as in vertical boring.

Most reciprocating surface grinding machines are comparatively small and are particularly suited to the grinding of small ferrous components when these are mounted on a magnetic chuck. Suitable loading times are given in Table 9. Wheel overrun must be allowed for as in milling, and table manipulation, covering all movements, may be taken as occupying about thirty seconds per load. Wheel dressing time must be allowed for and may be estimated as 10% of the grinding time.

Some difficulty is sometimes experienced in planning the most efficient table layout for rotary surface grinding. Until this is done the number of components per load is not known and hence it will be impossible to arrive at a floor to floor time. It is often helpful to make a rough outline of the component on tracing paper and manipulate this over a plan of the machine table, allowing, of course, a suitable clearance around each component for the mounting of the fixtures. If a magnetic table is used this latter condition does not apply but the recommended load as stated by the manufacturer should be adhered to.

A suitable speed in feet per minute can now be decided upon since the mean diameter formed by the ring of components mounted in their position on the table can be calculated.

CHAPTER IV.

FURTHER MACHINING PROCESSES.

Planing, Shaping and Slotting Machines.

Planing, shaping and slotting machines, by their very design, waste a considerable amount of time in idle return strokes. These machines therefore find little place in large scale production but are useful for jobbing and in the smaller batch factories. An exception to this may be made in the case of the planing machine where the work is often of such large dimensions that no other machining method is possible.

Surface grinding, milling and broaching are largely used as alternatives in mass production to replace planing, shaping and slotting respectively.

Cutting speeds could be theoretically similar to high speed drilling but since every reciprocating machine takes a small amount of time to attain its working speed on the cutting stroke and a corresponding time to decelerate before making the return motion, actual speeds are considerably less.

A simple formula for estimating tool travel in feet per minute is :—

$$T = \frac{2 \times \text{number of strokes per minute} \times \text{length of stroke in ins.}}{12}$$

$$= \cdot 167 \text{ NL.}$$

This expression, however, usually needs modifying since most return strokes are made at a faster rate than the forward cutting stroke. The exact ratio of forward to return stroke, expressed as a decimal, is available from the manufacturers of the machine. For the purposes of example let the ratio of the forward stroke be p and that of the return stroke q, then

Cutting speed, T (in feet per minute) $= \cdot 167 \text{ NL}q$

$$\text{or} \qquad N = \frac{T}{\cdot 167 \text{ L}q}$$

Similarly the time for the complete stroke will be

$$T \text{ forward} + T \text{ return}$$

$$= \left(\frac{1}{N} \times q\right) + \left(\frac{1}{N} \times p\right)$$

Most modern machines are capable of approaching 60 - 75% of normally accepted cutting speeds but many slotting machines work less efficiently.

Setting time will vary from about 15 minutes for a simple job on a slotter to a day or more for a heavy casting on a large planing

machine. Little guidance of any practical value can be given here since the range of work normally handled by these machines is very wide and each job must be studied individually.

Gear Cutting.

There are several methods of manufacturing gears and the advantages and limitations of each should be clearly understood by the process planner, since a gear made by one method will often not run successfully with a mating gear made by another.

There are about six common methods of producing gears, known respectively as the form milling method, usually associated with the Brown & Sharpe Mfg. Co., the hobbing process, the gear shaping method originated by the Fellows Gear Shaper Co., two methods of rack planing known severally as the Sunderland and the Maag, and finally the Gleason generating process as applied to bevel gears. There are also several profile grinding machines available but these will not be considered here.

All the methods are suitable for cutting straight spur gears except the Gleason system. Similarly any method may be used to cut spiral and helical gears but the limitations as to maximum helix angle obtainable by each method should be closely studied since the range of possible angles is appreciably restricted in some cases. The Gleason system is specially designed for bevel gear production and as such is equally suitable for cutting straight or spiral bevels. Worm gears are normally hobbed or thread milled but where quantities are very small they may be screw cut in a lathe.

One of the earliest methods of producing spur gear teeth was by form milling which is now almost entirely superseded by more modern and faster methods. The process is still used, however, for "one-off" jobs or very small batches.

In practice the method consists of an end mill cutter having the form of the gear tooth space to be cut. Indexing is done in the normal way with a dividing head and in the case of helical gear production a universal milling machine is usually used, the table set over to the required angle of helix and the dividing head geared to the lead of the spiral to be cut.

A set of eight milling cutters is required to cover the full range for each pitch, the cutters being numbered 1 to 8 :—

No.	1	cutter	will	cut	teeth	135	to	rack
,,	2	,,	,,	,,	,,	55	to	134
,,	3	,,	,,	,,	,,	35	to	54
,,	4	,,	,,	,,	,,	26	to	34
,,	5	,,	,,	,,	,,	21	to	25
,,	6	,,	,,	,,	,,	17	to	20
,,	7	,,	,,	,,	,,	14	to	16
,,	8	,,	,,	,,	,,	12	to	13

It is impossible by milling to undercut the teeth of small pinions and an alternative method is used to eliminate interference. Gear teeth thus form milled are not of true involute shape above the base circle and therefore will not mesh successfully with gears made by methods capable of giving geometrically accurate tooth forms.

The cutting of either straight, helical, spiral or worm gears by hobbing is a well-known process and now with the comparatively recent introduction of successful climb hobbing is becoming a serious competitor to all other methods for fast, accurate work.

The distinguishing feature separating the hobbing machine from all other forms of gear cutters is that the teeth are produced by the simultaneous rotation of the cutter, or hob, and the gear being cut. The cutting is continuous and there is no expensive and complicated intermittent indexing mechanism and no reciprocating cutter.

Hobbing machines are designed with the hob swivel slide mounted either horizontally as in the Barber-Colman or vertically as the Cleveland, Craven and others. The principle is the same and there is little to choose between either type. Helical gears may be cut on a machine primarily intended for spur gear production up to a limit of about 30° helix; above this figure the universal type of machine should be used.

The practical limitations of the process lie not so much with the machine but with the actual design of the component itself. Sufficient clearance will always be required for the run out of the hob, Fig. 8. This effectively excludes the production of cluster gears and components having gears close to shoulders. The situation is of significance when planning straight spur gears but when spiral gears are considered, when the hob has to be set over to the required helix angle, the trouble is further aggravated. Sometimes the determination of the approximate clearance to provide needs to be solved by the accurate laying out of elipses. The various manufacturers of hobbing machines are successfully overcoming these disadvantages to a certain extent by perfecting the in-feed, or plunge, method of hobbing in place of the conventional longitudinal traverse feed, Fig. 9.

It should be noted that having determined the correct feed rate for cutting spur gears (which depends upon the pitch besides the usual considerations) feed for cutting helical and spiral gears will decrease as the helix angle increases. For angles from 0° to 36° feeds may be as for spur gears, but for angles 36° to 48° the feed should equal $\frac{4}{5}$ of that for spur gears, from 48° - 60° $\frac{2}{3}$ of the spur gear feed, from 60° - 70° one half, and for angles above 70° one-third of the feed.

Appreciably greater outputs, especially when roughing, may result from the use of multi-start hobs, which mean higher speeds of the work table when using the same hob speed as for the single

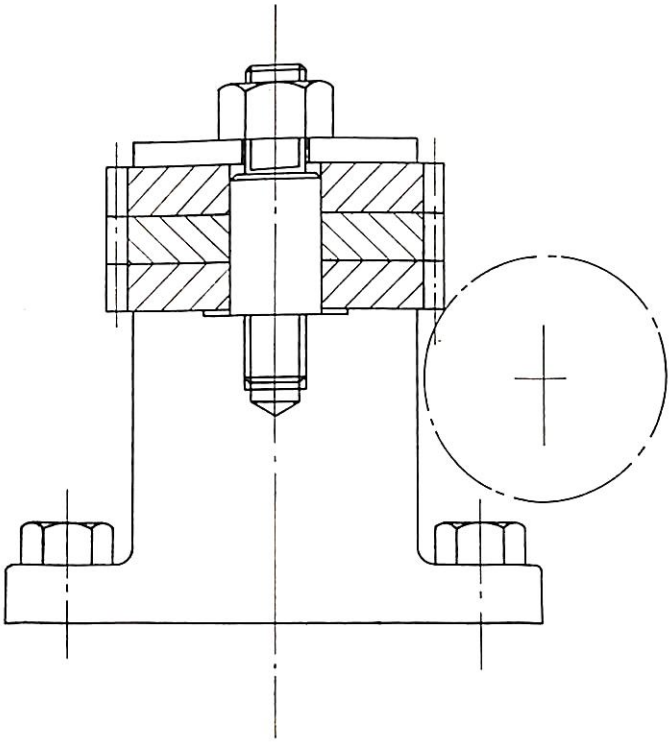


Fig. 8.

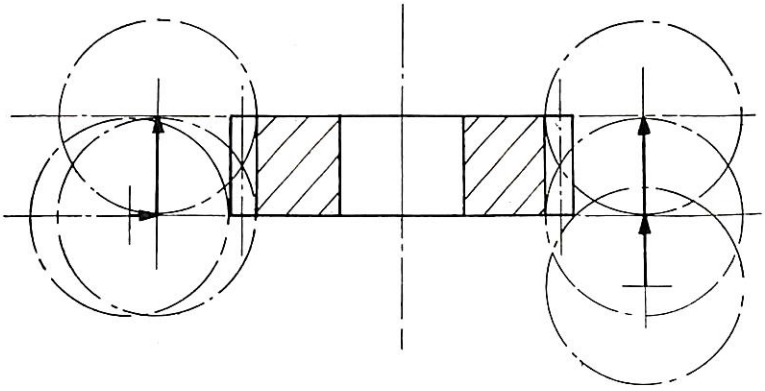


Fig. 9.

start tool. Besides this, feeds may be higher due to the more favourable cutting action of multi-start hobs. The increase in output that can be expected will be about 60% greater for two start hobs and 100% greater for three start hobs.

Handling time is small compared with actual machining time and a 5% contingency allowance is all that is normally needed.

Gears may be machined in one of the three following methods :—

(*a*) Rough and finish with same hob in two cuts (with or without feed change).
(*b*) Rough with roughing hob, finish with finishing hob.
(*c*) Rough and finish in one cut.

It is recommended that method (*a*) be used for machining heavy pitch gears in small quantities ; (*b*) for similar gears in large quantities (two machines would normally be used), and (*c*) for cutting gears of light pitch. It should be noted that method (*b*) requires double the handling time of method (*a*) but is economical in many cases.

Machining time, T, is given by,

$$T = \frac{N \times (W+O)}{F \times S \times H}$$

where,

N = number of teeth in the gear.
W = face width of gear or gears.
O = overtravel of hob.
F = feed in inches per revolution of gear.
S = speed of hob in revolutions per minute.
H = lead of hob.

As many as eight or more blanks of narrow face width may be mounted together on the arbor for cutting at one pass except where a hub extends more than about $\frac{1}{8}$ in. beyond the face width when it is advisable to mount two blanks back to back.

Typical handling times for the Barber-Colman type machines are given in Table 10.

The same hob as used for spur gears may be used for helical and spiral gears provided the normal pitch and pressure angle of the hob is the same as the gear in the normal plane.

Another widely used method of gear manufacture is the shaping process. This is particularly useful for the production of cluster gears, etc., which are either difficult or impossible to produce by hobbing.

A circular cutter is used which represents a spur pinion but with the necessary side and front clearances added. The cutter addendum is made equal to the dedendum of the gear.

Due to the necessity for a front clearance on the cutter the Shaping process will not impart an accurate pressure angle to the

component. The error admittedly is only slight being of the order of about ten minutes or so of arc but nevertheless sufficient to preclude smooth and silent running when meshed with gears made by another process.

Two sizes of cutters are used in average work, namely, 4 inches pitch diameter for spur gears of 6 diametral pitch and coarser, and a 3 inch pitch diameter cutter for spur gears of 7 diametral pitch and finer.

Helical gears may be cut by fitting a helical guide assembly in place of the usual straight guide used for spur gears. Right and left handed guides are necessary for gears having a right or a left hand helix; the hand of the guide is always the same as the hand of the cutter while the hand of the cutter is invariably opposite to the hand of the gear to be cut.

Two standard guides are available giving approximate angles of helix of 15° and 23° respectively. The design however is unsuitable where the angle is greater than 35°. For angles greater than this figure an alternative method of gear cutting must be chosen. Should it be required to cut a gear of an angle other than either 15° or 23° but within the range of the machine, *i.e.*, 0° - 35° it would be necessary to provide special guides and cutters to conform to the desired helix.

When calculating production times first decide upon the speed (number of strokes per minute) and the feed from Table 11, then calculate time, T_1, for the cutter to feed in to depth, *i.e.*, before the commencement of the rotary motion, by formula,

$$T_1 = \frac{D}{0{\cdot}0018 \times S}$$

where, D = whole depth of tooth in gear to be cut.
S = number of strokes per minute.

The value thus obtained should then be added to the total time to make one complete revolution of the gear, thus giving the total machine cycle time.

Time to make one complete revolution of work, T_2, is given by,

$$T_2 = \frac{s \times P}{S}$$

where s = strokes of cutter per inch of pitch diameter of cutter (see Table 12).
P = pitch diameter in inches of gear to be cut.
S = number of strokes per minute.

It is a well-known fact that the involute rack is theoretically a very small section of arc of circumference of a gear having infinite pitch circle diameter. This is true whether the gear be spur or helical. It follows then, that instead of cutting a gear by means

of rolling in conjunction with a pinion cutter, as has just been considered, it should be possible to cut a like gear by rolling it in conjunction with a cutter of rack formation. This is the principle of the planing method.

The two systems in general use, as already stated, are the Sunderland and the Maag. Although the work spindle on the Maag machine is disposed vertically and on the Sunderland it lies in a horizontal plane, and further the indexing mechanism is slightly different between the two machines, the basic principle of operation remains the same. A notable dissimilarity is to be found in the cutters and cutter boxes. The Sunderland cutter is hollow ground, has 6° front clearance, no top rake and the included angle of the cutter teeth is made equal to twice the pressure angle. The Maag cutter similarly has no top rake but is disposed at $6\frac{1}{2}°$ in the cutter box thus giving an effective rake of $6\frac{1}{2}°$. The front clearance is 12° to compensate for the angular displacement. Due to the $6\frac{1}{2}°$ inclination the pressure angle of the cutter is slightly smaller than the pressure angle of the gear to be cut.

Both cluster and shoulder gears may be machined by planing but it is usually necessary to design a special extended cutter box and also to prepare a layout for the determination of clearances in the case of helical gears.

Double cutting is sometimes provided with the Sunderland machine, two cutter boxes being mounted on the reciprocating cutter slide, one cutter being arranged to cut on the normal working stroke and the other cutting a further set of gears, suitably mounted on the arbor, on the return stroke.

In the majority of cases both spur and helical gears may be cut with equal facility on the same machine, and cutters may also be similar provided the pitch of the spur gear is the same as the normal pitch of the helical gear.

Gear planing machines are available in very large capacities for handling marine turbine gears and similar heavy work.

It is important to use only accurately machined blanks in all forms of gear cutting but in bevel gear manufacture this is even more desirable. The machining of these latter blanks requires close control if a silent running and interchangeable product is to be produced. Untold time may be wasted upon assembly by the need to grind the back face of an inaccurate gear or pack another with shims in an effort to secure the designed backlash and centre distances.

Fig. 10 shows a typical bevel gear with suitable tolerances on dimensions indicated. All angles should be as accurate as commercially possible, *i.e.*, to within a very few minutes of arc. Obviously the bore should be concentric with the outside diameter and perfectly square with the back face.

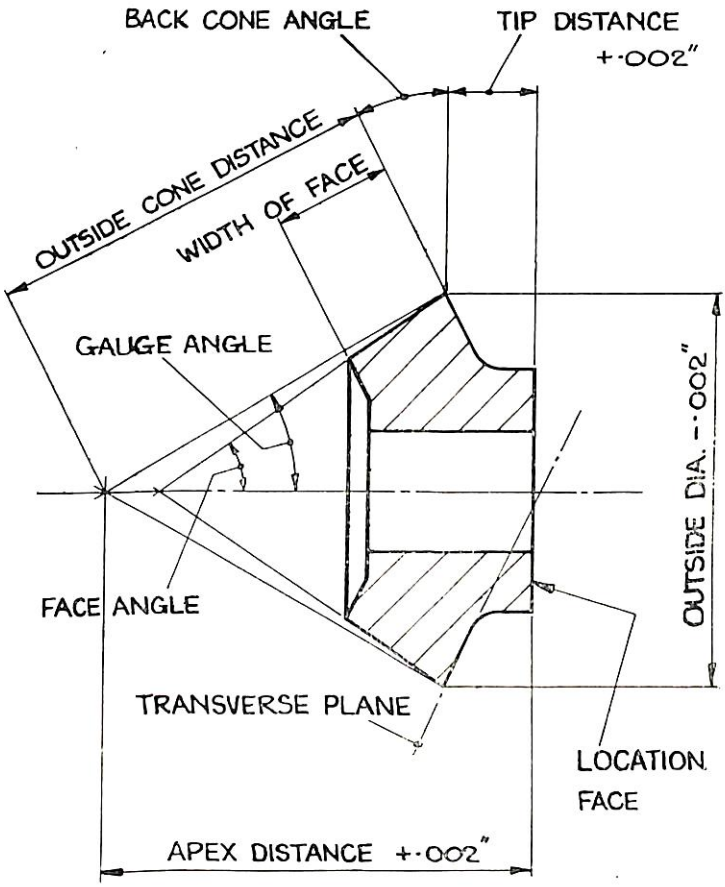


Fig. 10.

The process planner should call for rough turning of the blanks to leave about ·020 in. - ·025 in. on face and back angles, locating the component from the bore or shank and the back face.

Although there are several makes of machines in existence for cutting bevel gears, the only one of importance is the Gleason.

For small batch production it is usual to either rough cut at one setting and then re-set for the finishing operation on the same machine, or form mill with a dividing head or otherwise and then finish on the gear cutter. It should be noted, however, that where the shape and size of the tooth space at the front end differs greatly from the tooth space on the transverse plane, it is not economical to rough on a milling machine and the work is then necessarily done on the gear cutter.

Form milling, using the dividing head, is too slow for mass production and advantage may be taken of the Gleason Revex gear rougher or the later Gleason, design the Revacycle. Both these machines incorporate a large diameter inserted blade type milling cutter but the latter is entirely automatic, being designed to load and unload itself apart from performing the actual machining cycle automatically.

Double indexing, *i.e.*, indexing two teeth per movement can be used for roughing on the normal Gleason gear generator where the number of teeth to be cut in the blank is about thirty or over, when a reduction in machine cycle time of about 40% can be anticipated.

Although three standard pressure angles, namely $14\frac{1}{2}°$, $17\frac{1}{2}°$ and 20° have been adopted for bevel gear design it is possible to cut other pressure angles using the standard cutters. It is preferable, of course, to use a cutter having the same pressure angle as the gear to be cut but if a suitable cutter is not available, or for some other reason the ideal is not possible, it is practicable to cut a pressure angle slightly larger than that of the cutter being used. For example, a standard $14\frac{1}{2}°$ pressure angle cutter will cut a $17\frac{1}{2}°$ pressure angle and so on.

Finishing and roughing cutters used for single indexing are practically identical except that the finishing cutters have side relief and the roughing cutters have not.

Broaching.

The broaching of keyways and serrations, etc., is a well-known process, but it is not always realised to what extent this machining method has developed during recent years. Internal helical involute gears may now be broached complete in one pass and flat surfaces machined at appreciably faster rates than conventional slab milling.

Broaching is, in many cases, the only practical method of producing irregularly shaped holes particularly where these are of considerable length. By the addition of a few burnishing "teeth" at the end of the broach a formed hole may be rough and finish cut and super finished to a few micro inches, the whole operation being performed in one pass.

All holes, irregular or otherwise, may be started from holes which have been cored, forged, punched, drilled, bored, reamed or otherwise prepared. It is unnecessary to start from an accurately formed hole provided a suitably designed broach is used to deal with the particular condition.

Broaches are of two main types, internal and external, and both of these types may be designed so that the tool is either pulled or pushed through or over the work. The smaller types are made from high speed steel, the larger are often built up in sections.

Where it is economic to do so, the inserted type of tooth is used, composed of either high speed steel or tungsten carbide.

Push broaches are necessarily short and therefore cheaper in first cost, but one pull broach usually removes as much stock as several push broaches. Most modern broaches are arranged to be pulled.

An interesting development is progressive broaching. This system is very effective for machining a flat or internal surface on castings or scaly forgings. The broach is given one or more rows of teeth, narrower than the surface to be finished. These rows are fanned out at an angle with the longitudinal axis of the broach so that full width is machined only by a complete pass of the broach. Each tooth cuts full depth but only an increment of the width. The action of such a broach is to notch the hard abrasive casting skin and cut into machinable metal below. As the broach advances the notch is widened progressively by virtue of the fan formation of the teeth until full width is gained near to the end, where finishing teeth may be provided of the normal full width type.

A progressive broach is capable of producing 70% or more components before regrinds than is the conventional slab broach. A further advantage is gained in that power requirements are reduced but the length of the broach is increased and it is this length that becomes the limiting factor on very wide surfaces.

Inserted tooth and built-up broaches are constructed for similar reasons that such construction is used in other tools, *i.e.*, to conserve costly material such as high speed steel, to provide support for the cutting edge that is tougher and more shock resistant than the edge material, to provide limited size adjustment to compensate for sharpening, to permit replacement of individual teeth and to permit a broach construction which is simpler and easier to make, hence less costly than a solid broach.

A variant of the built-up type is the shell broach designed for internal holes. This broach consists of an accurately ground centre arbor upon which are threaded the sections containing the teeth which together make up the complete broach. These sections when assembled are locked solid with the arbor by means of a pair of lock nuts.

Broach design is the province of the jig and tool designer, but since the process planner must know the approximate length and power required to broach a particular component before he can allocate a suitable machine to this duty he must be familiar with some of the fundamental principles involved.

Obviously the length of the broach must not be longer than the stroke of the machine. Pitch, P, is a function of the length and is given by,

$$P = \cdot 35\sqrt{\text{length of cut}}$$

It is important that at least two teeth, preferably more, are cutting at any one instant. Sometimes very thin components can be strung together so creating a greater effective length of cut.

Having provisionally decided upon the pitch it is intended to use, an approximate length for the broach can be calculated taking the depth of cut per tooth as ·003 in. - ·005 in. on diameter. Check that the stroke of the machine is sufficient to accommodate the length also that the power is adequate.

In computing horse-power requirements consideration must be given to the type of work being done, *i.e.*, surface, internal spline or round hole. A formula for each is given below.

Surface broaching,

$$\text{Pull in tons} = \frac{W \times R \times K}{2240}$$

where W = sum of lengths of all teeth engaged at any instant in inches (depends upon pitch and shape of component, see Fig. 11).
R = rise per tooth (*i.e.*, chip thickness).
K = constant.

Internal spline broaching,

$$\text{Pull in tons} = \frac{N \times S \times W \times R \times K}{2240}$$

where N = number of teeth engaged.
S = number of splines.
W = average width of spline in inches.
R = rise per tooth on broach radius.
K = constant.

Round hole broaching,

$$\text{Pull in tons} = \frac{N \times D \times R \times K}{2240}$$

where N = number of teeth engaged.
D = diameter of hole in inches.
R = rise per tooth on broach radius.
K = constant.

In the formulae K for alloy steel may be taken as 600,000, mild steel 450,000, malleable iron 400,000, cast iron 350,000, and all non-ferrous metals 300,000.

With the horse-power requirements known and using a cutting speed of 20 - 30 feet per minute, the process planner should be in a position to estimate whether it is economically desirable to machine the surface of a flat component by grinding or slab milling or whether to surface broach.

As mentioned, the broaching of internal holes is often the only machining method possible, but where alternatives do exist broaching is almost invariably to be preferred, and on this account an estimate for comparison is usually not required.

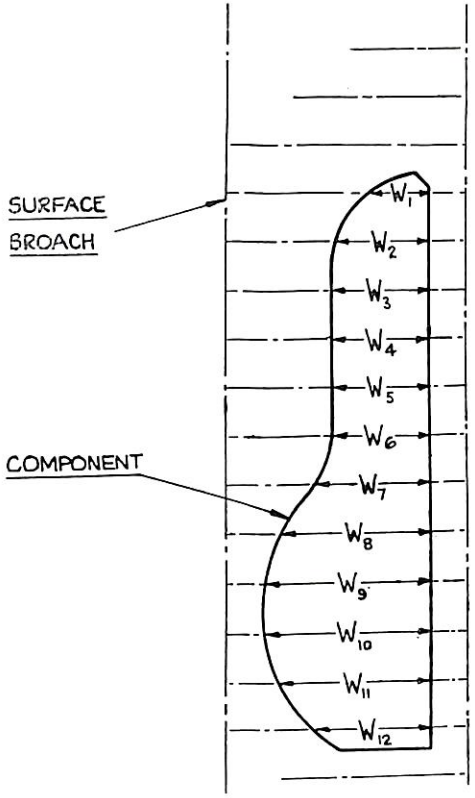


Fig. 11.

CHAPTER V.

PLANNING A TYPICAL COMPONENT.

Having discussed at some length the major machining processes as used in the metal working industries, and studied a typical operation sequence for a simple component produced in each of the three production methods, it is now proposed to consider the planning technique used in the mass production of a fairly complex piece part.

Fig. 12 shows a drive gear made from 2% nickel molybdenum case hardening steel and included in the text is the operation layout governing its processing.

This gear, whilst resembling in many respects similar components quantity produced in the automobile and related industries, has, nevertheless, been especially designed here for the purpose of illustrating the use of each of the more common machining operations. It is to be produced right from raw billet to the finished product.

Operations Nos. 1 - 40 refer to forge shop work and entail the cold sawing of billets from black bar into appropriate lengths and up-setting at one end to form the large gear diameter.

The first machining operation is done on a Herbert capstan where the part is faced, turned, centred and rough drilled. It will be appreciated that the normal capstan lathe is not usually considered a mass production machine but more suited to batch work. For rapid production, machines such as the Herbert Auto Lathe or the Ryder Verticalauto might be considered the more suitable. However, the component in this case requires some deep hole drilling and unless the automatic machine can be fitted with some form of automatic relieving cycle so that the drills can be withdrawn several times to clear chips the process is best controlled by human agency. Note the use of the combination drill and the combination drill and reamer, enabling two diameters respectively to be cut simultaneously. The first combination drill cuts to a calculated depth such as will permit cleaning up by the subsequent flat bottom drilling. At this operation the $2\frac{1}{2}$ ins. shoulder diameter is turned to serve as location for the next operation which is a straightforward one where the back end is faced and drilled and is planned to be put on a Ryder Verticalauto.

Before rough and finish turning the various diameters on automatic centre lathes, a driving slot is required and accordingly a rough gash is provided for this purpose by milling at Op. No. 55.

The turning may now follow. Note that at Op. No. 65, a carburizing allowance is left on the $1\frac{1}{8}$ B.S.F. diameter for subsequent removal prior to hardening and that at Op. No. 70 and

(*continued on page* 55)

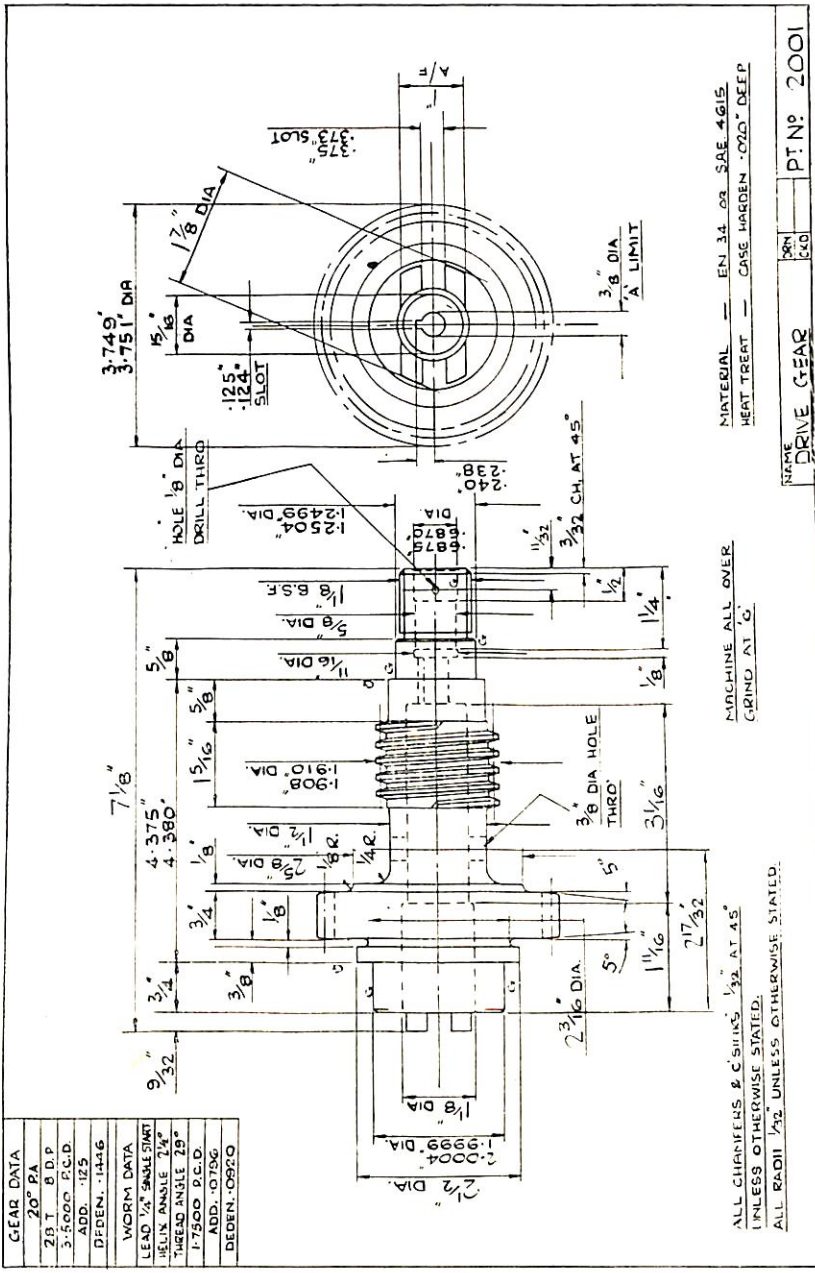

GEAR DATA
20° PA
28 T 8 D.P
3·5000 P.C.D
ADD. ·125
DEDEN. ·1446
WORM DATA
LEAD 1/4" SINGLE START
HELIX ANGLE 2°4"
THREAD ANGLE 29°
1·7500 P.C.D.
ADD. ·0756
DEDEN. ·0920
3.749'
3.751' DIA
7 1/8"
4·375"
4·380'
HOLE 1/8" DIA
DRILL THRU
·125"
·124"
SLOT
·375"
·373" SLOT
1 7/8 DIA
3/8" DIA
'A' LIMIT
MACHINE ALL OVER
GRIND AT 'G'
3/8 DIA HOLE
THRO'
ALL CHAMFERS & C'SINKS 1/32" AT 45°
UNLESS OTHERWISE STATED.
ALL RADII 1/32" UNLESS OTHERWISE STATED.
MATERIAL — EN 34 OR SAE 4615
HEAT TREAT — CASE HARDEN ·020" DEEP
NAME
DRIVE GEAR
PT. Nº. 2001

Fig. 12.

OPERATION SCHEDULE.

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
1	Saw off to length	Noble and Lund			Vee clamps	·45
5	Set tools for upset forging complete	5″ National Forging Machine			Upset forging tools	·90
10	Heat to 1200°C. and upset forge complete	Drop Hammer			Tongs, skip	·80
15	Cold clip	Hand Press				·45
20	Grind flash	Floor grinder			Gloves, goggles	·50
25	Clip and file if necessary	Bench				·75
30	Normalize at 920°C.	Furnace			Asbestos gloves	·60
35	Shot blast clean	Wheelabrator			Gloves, standard shot	·40
40	Rough view	Bench				D.W.

Put on Conveyor for Transit to Machine Shop.

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
45	Load in chuck on small end	Herbert No. 4 Capstan Lathe			Knee turner and T.C. tool	
	Rough turn $2\frac{1}{2}''$ dia. to $\frac{2{\cdot}564}{2{\cdot}561}$					
	in. dia. × $1\frac{7}{16}''$ long		140	·010	Centre	
	Rough face end to leave $\frac{1}{8}''$ on and centre		140	·010	T.C. facing tool (3) drill sockets (4) tool holders	
	Drill $\frac{7}{8}''$ dia. × $2\frac{1}{2}''$ deep		260	·010	$\frac{7}{8}''$ dia. drill	
	Combination drill $1\frac{3}{32}''$ dia. and $\frac{7}{8}''$ dia. × $5\frac{7}{32}''$ deep to drill point				$1\frac{3}{32}''$ comb. drill	
			200	·009	$1\frac{7}{64}''$ comb. reamer	
	Combination ream $1\frac{7}{64}''$ dia. and drill $\frac{15}{16}''$ flat bottom × $5\frac{5}{32}''$ deep		150	·025		8·65
50	Location off $\frac{2{\cdot}564}{2{\cdot}561}$ ins. dia.	Ryder			Facing tool	
	Face other end to give $7\frac{3}{8}''$ overall length and centre	Verticalante No. 6	150	·020	$\frac{21}{32}''$ dia. drill and socket $\frac{7}{8}''$ dia. drill and socket	
	Drill $\frac{21}{32}''$ dia. × $\frac{5}{8}''$ deep and c'sink to form centre for subsequent ops.		305	·010	Letter 'U' drill & chuck Recessing attachment	
	Drill $\frac{5}{8}''$ dia. × $1\frac{9}{16}''$ deep		366	·010	Boring bar and tool	
	Form recess $\frac{11}{16}''$ dia. × $\frac{1}{8}''$ wide to drg.		305			
	Bore $\frac{·676}{·678}$ in. dia. × $\frac{5}{8}''$ deep		366	·008		
	Drill letter 'U' (·368" dia.) to break through		600	·006		·33

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
55	Mill $\frac{\cdot 375}{\cdot 373}$ in. slot to $\frac{5}{16}$″ wide × $\frac{1}{4}$″ deep	Cincinnati 1 - 18 Auto	63	·032	Fixture (air clamp) $\frac{5}{16}$″ × 3″ × 1″ cutter Spacing collars	2·45
60	Drive from small forged dia. and tailstock centre Note $\frac{1}{8}$″ left on rough faced end Rough turn $1\frac{7}{8}$″ dia. ,, ,, $\frac{2\cdot 0004}{1\cdot 9999}$ ins. dia. ,, ,, $2\frac{1}{2}$″ dia. ,, ,, large gear dia. and chamfer Rough form $\frac{1}{8}$″ rad. on $2\frac{5}{8}$″ dia. Leave $\frac{1}{16}$″ on all diameters and $\frac{1}{32}$″ on faces	Maximinor 6 × 18	65	·010	'Maxi-grip' driver Plug tailstock centre to suit $1\frac{7}{64}$″ dia. reamed bore Rear tool blocks H.S.S. tools Front tool blocks	2·05
65	Drive from $\frac{5}{16}$″ wide slot Rough turn $1\frac{1}{8}$″ B.S.F. dia. to $1\frac{1}{4}$″ dia. Rough turn $\frac{1\cdot 2504}{1\cdot 2499}$ ins. dia. ,, ,, $1\frac{1}{2}$″ dia. (two places) ,, ,, worm gear dia. ,, ,, $2\frac{3}{16}$″ dia. Leave $\frac{1}{16}$″ on all diameters except where otherwise stated	Maximinor 6×18	65	·010	Driver to suit slot Std. tailstock centre Front tool blocks Rear tool blocks H.S.S. tools	2·43

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
70	Drive from $1\frac{1}{4}''$ dia. and tailstock centre Finish turn $1\frac{7}{8}''$ dia. Semi-finish $\frac{2{\cdot}0004}{1{\cdot}9999}$ ins. dia. to $\frac{2{\cdot}0104}{2{\cdot}0099}$ ins. dia. Finish turn $2\frac{1}{2}''$ dia. Finish gear blank dia. to $\frac{3{\cdot}7495}{3{\cdot}7500}$ and chamfer Finish turn $2\frac{5}{8}''$ dia. forming $\frac{1}{8}''$ rad.	Maximinor 6×18	83	·007	'Maxi-grip' driver Plug tailstock centre to suit $1\frac{7}{64}''$ dia. reamed bore Front tool blocks Rear tool blocks H.S.S. tools	2·21
75	Drive from $\frac{5}{16}''$ wide slot Semi-finish turn $\frac{1{\cdot}2504}{1{\cdot}2499}$ ins. dia. to $\frac{1{\cdot}2604}{1{\cdot}2599}$ ins. dia. Finish turn $1\frac{1}{2}''$ dia. (two places) Finish turn worm gear dia. $2\frac{3}{16}''$ dia.	Maximinor 6×18	83	·007	Driver to suit slot Std. tailstock centre Front tool blocks Rear tool blocks H.S.S. tools	2·21

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
80	Finish gang mill slot $\frac{\cdot 375}{\cdot 373}$ in. wide, 1″ A/F × $\frac{9}{32}$″ deep to give $7\frac{1}{4}$″ O/A length	Cincinnati Hydromatic	50	·032	Fixture Cutter gang	2·85
85	Inspect	Bench				D.W.
90	Cut (28) teeth 8 D.P. 20° P.A. rough and finish in two revolutions at one setting	Fellows Gear Shaper	200 strokes/min.	Med.	Fixture locating from $\frac{2\cdot 0104}{2\cdot 0099}$ ins. dia and $2\frac{1}{2}$″ dia. shoulder face	6·07
95	Load at station Mill worm gear $\frac{1}{4}$″ lead single start, helix angle $2\frac{1}{2}$°, thread angle 29° Finish in one operation	Lees-Bradner 4-Station Vertical Hobber	120	·015	(4) hobs	1·7
100	Load in fixture Profile outer face of gear	Hey tooth rounder			Fixture Cutter	1·2
105	Load in fixture Profile inner face of gear	Hey tooth rounder			Fixture Cutter	1·2
110	Fraze where necessary	Bench			6″ half-round file Wire brush	1·0
115	Inspect	Parkson gear tester				D.W.

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
120	Degrease. Clean for 20 mins.	I.C.I. Degreaser			Wire basket, gloves solvent	·2
125	Carburize 900/920°C. ·020″ depth of case	Homocarb Furnace				2·4
130	Turn $1\frac{1}{8}$″ dia., form undercut Face to give $7\frac{1}{4}$″ overall length Screw $1\frac{1}{8}$″ B.S.F. and chamfer Chamfer bore $\frac{1}{32}$″ × 45°	Ward No. 3 Capstan	200 200	·009 hand	Roller box and tool Facing tool Coventry Die Head Set $1\frac{1}{8}$″ B.S.F. dies Chamfer tool	2·3
135	Broach $\frac{3}{8}$″ dia. 'A' limit and $\frac{3}{32}$″ wide slot to drg.	Lapointe Pull-down vertical broaching machine		·003 per tooth	Automatic broach retractor	·5
140	Drill (1) hole $\frac{1}{8}$″ dia. through Drill (1) hole $\frac{3}{8}$″ dia. through	Asquith 2 Spin Sensitive	($\frac{1}{8}$″) 1830 ($\frac{3}{8}$″) 610	·002 ·006	Rollover jig $\frac{1}{8}$″ dia. drill $\frac{3}{8}$″ dia. drill Suds brush	·75
145	Harden 820°C. Preheat for 30 mins. Transfer to cyanide bath, soak for 30 mins. Drain off. Quench in oil.	Preheater Kasenit Salt Baths			Wire basket	·4
150	Wash	Wash tank			Wire basket	·4
155	Temper 150°C.; soak for 90 mins.	Temper furnace				·6
160	Vapour blast clean	Curren				2·8
165	Wash	Wash tank			Wire basket	·4
170	Inspect for hardness and damage	Bench			Rockwell hardness tester	D.W.

OPERATION SCHEDULE—*continued.*

Op. No.	Description of Operation	Machine Name	Speed R.P.M.	Feed Ins./Rev.	Equipment	Est. F to F (Mins.)
175	Hold on O/D of gear and set true. Grind $\frac{\cdot 6875}{\cdot 6870}$ in. dia. bore	Heald Internal Grinder	Wheel 5,500 Work 140		Collet chuck Collet pads for 3·750″ diameter grinding wheel	1·75
180	Hold on O/D of gear and set true. Grind $1\frac{1}{8}$″ dia. bore to $\frac{1\cdot 1250}{1\cdot 1245}$ ins. dia.	Heald Internal Grinder	Wheel 5,500 Work 90		Collet chuck Collet pads for 3·750″ diameter grinding wheel	1·75
185	Press in plugs. Load on centres. Finish grind $\frac{2\cdot 0004}{1\cdot 9999}$ ins. dia.	Churchill Cylindrical Grinder	Wheel 2,000 Work 50		Plugs 10″ dia. × 1″ grinding wheel	1·90
190	Press in plugs. Load on centres. Finish grind $\frac{1\cdot 2504}{1\cdot 2499}$ ins. dia.	Churchill Cylindrical Grinder	Wheel 2,500 Work 50		Plugs 8″ dia. × 1″ grinding wheel	1·25
195	Mount on arbor Run-in spur gear	Running-in Machine			Arbor	2·00
200	Mount on arbor Run-in worm gear	Running-in Machine			Arbor	2·00
205	Mount on arbor. Test spur gear for silent running Stone where necessary	Red Ring gear speeder			Arbor carborundum slip	1·00
210	Mount on arbor. Test worm gear for silent running Stone where necessary	Red Ring gear speeder			Arbor Carborundum slip	1·00
215	Final inspect and stamp	Bench			Punches Hammer	D.W.

Place on Conveyor for Transmission to Assembly Shop.

No. 75, those diameters requiring a ground finish, as indicated on the component drawing, are only semi-finished here with an allowance left on for later grinding to size.

After completing these turning operations the driving slot is no longer required and may be finished milled to drawing dimensions (Op. No. 80).

An inspection station follows where special attention should be paid to the concentricity of important bores and diameters with the gear blank diameters before passing to Op. No. 90.

This is the first gear cutting operation. The process planner should check the purpose of the $\frac{2{\cdot}0004}{1{\cdot}9999}$ ins. dia. It will probably be found that it is intended for the mounting of a ball race, its partner being the $\frac{1{\cdot}2504}{1{\cdot}2499}$ ins. dia. Under these conditions, therefore, it is important to ensure that the gears are cut accurately concentric with the bearing diameters. To ensure that this will be the case, a gear cutting fixture is called for to locate off the $\frac{2{\cdot}0004}{1{\cdot}9999}$ ins. dia. which has a grinding allowance upon it at this stage, and the $2\frac{1}{2}$ ins. dia. shoulder face. It might be clamped by a single stud passing right through the component.

The thread milling of the worm gear is equally important. Apart from concentricity precautions, care should be taken to ensure that a cutter is used that will not interfere with the spur gear diameter when running out.

Operation Nos. 100 and 105 are devoted to gear tooth chamfering and are followed by hand frazing at Op. No. 110.

Having machined thus far, the part is now ready to be carburized. After the carburizing operation but before actual heat treatment the carbon case must be removed from areas which are required to be left soft. This will apply to the $1\frac{1}{8}$ B.S.F. thread, also the cross drilling and the broaching operations must be completed prior to hardening.

Since only ·020 in. depth of case is called for on the component drawing, all the carbon will be effectively removed by reducing the $1\frac{1}{4}$ ins. dia. down to $1\frac{1}{8}$ ins. dia. for screwing and by facing $\frac{1}{8}$ in. off the end face. Subsequent heat treatment, therefore, can have no effect on these areas. This, of course, applies to a limited extent to the broaching and drilling operations.

After these operations then, which are numbered 130 - 140, heat treatment follows together with tempering back to 150°C.

The component is now cleaned and inspected before the final grinding. Using the gear diameter, the $\frac{\cdot 6875}{\cdot 6870}$ in. dia. bore is finished at Op. No. 175 and after turning the component round the $1\frac{1}{8}$ ins. dia. bore is finished to $\frac{1{\cdot}1250}{1{\cdot}1245}$ ins. dia. to act as location at Op. Nos. 185 - 190.

By locating from these two bores just ground at Op. Nos. 175 and 180, which should themselves now be concentric with the gear diameter, the ball race diameters at either end are finished thus ensuring concentricity with gear and bearing diameters.

Gear running-in machines and hand stoning follow and the whole component is finally inspected at Op. No. 215.

The foregoing is necessarily a brief description of but one method whereby this drive gear could be mass manufactured.

Like most layouts of a similar nature it does not necessarily represent the only method of doing the job, nor indeed can it hope to represent, for any appreciable time, the best and most efficient method since at all times it should be open to modification and improvement in the light of practical experience and technical development. Few efficient operation layouts ever reach the stage of finality. In the constant search for better methods to reduce costs and speed production, layouts should always be in an ordered state of controlled development.

CHAPTER VI.

PRESS AND SHEET METAL WORK PLANNING.

It is sometimes considered that large volume production is a requisite before presswork can be assumed an economic proposition and further, heavy expenditure is necessarily entailed in the manufacture of press tools which must be of the highest standard of precision.

This, of course, is by no means the case since many small batch production firms regularly use hand fly presses (or even simpler equipment) with the most modest tooling and achieve profitable results adequate for their purpose.

The jig and tool designer and more especially the specialist press tool designer, are each well versed in the many and varied types of tooling in regular use, both in mass and batch production, but it is intended to briefly describe the more important of these types in an attempt to indicate, at least, the technique of presswork throughout the industry. It will be realised that the process planner is responsible for deciding the optimum method to use in any circumstance and, having done so, he must be sufficiently confident to order all necessary tooling and allocate a suitable press to cover any given job.

Press Tool Design.

Two of the simplest types met with in presswork are illustrated in Figs. 13 and 14 respectively, the former showing a spring plate tool for blanking and the latter a bending tool designed for the reception of slugs or precut blanks. Both these tools are cheap to make and useful for very short runs. Operation time on the spring plate tool is rather slow, being about thirty seconds when used in conjunction with a fly press and about twenty seconds where a power press is used.

Production of blanks in the heavier gauges is facilitated, where it is permissible to depart slightly from the component design, by offsetting the blank in relation to the strip by a small increment of distance as indicated in Fig. 15. This will ease stripping of the waste material off the punch. Many hundreds of steel blanks up to about 16 S.W.G. can be expected during the life of a spring plate tool of this type.

Another cheap tool but designed for punching blanks of about 4 - 6 inches across in mild steel or harder material is the loose punch type shown in Fig. 16. This, like the spring plate, is rather slow, requiring about twenty seconds when used with a fly press and fifteen seconds with a power press. The difficulty of stripping, however, is not present since the punch drops right through the sheet or strip.

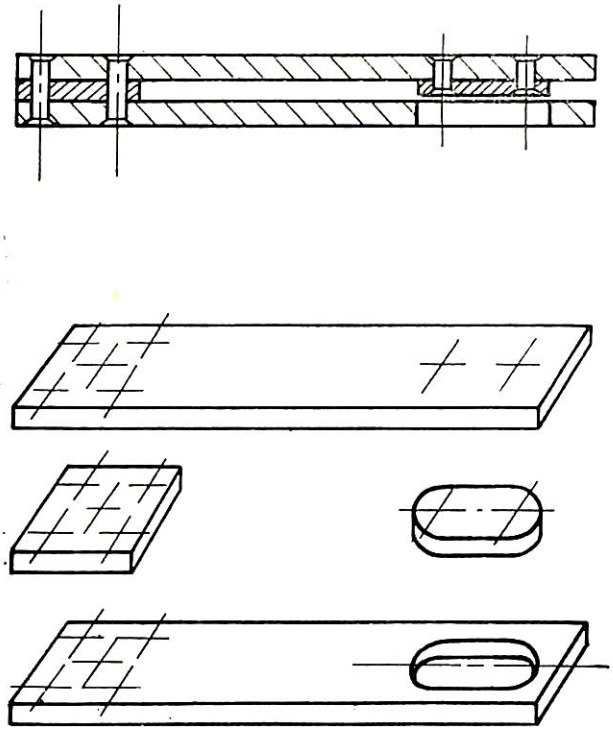


Fig. 13.

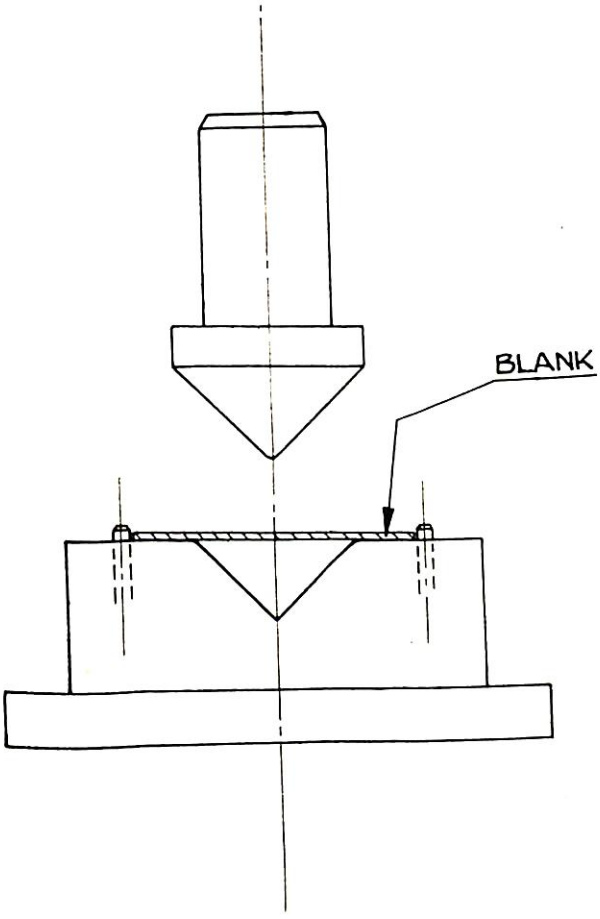


Fig. 14.

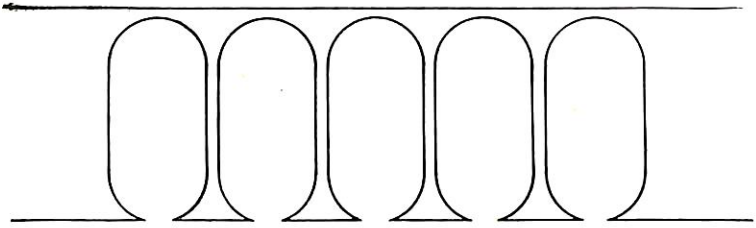


Fig. 15.

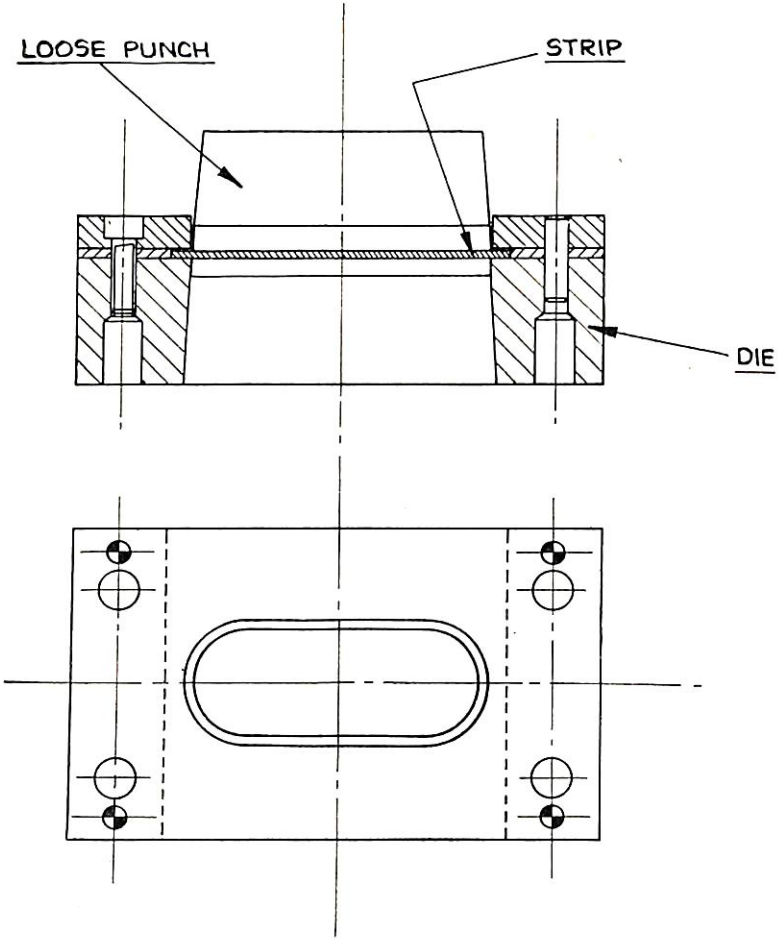


Fig. 16.

Where the material to be blanked is light alloy (as used in the aircraft industry) or where other relatively soft material is called for, a cheaper tool shown in Fig. 17 may be used. The operation time is considerably less than the two blanking methods previously referred to, being, apart from handling time, almost as fast as the stroke of the press. The method used is to lay the material on the top face of the die whereupon the punch descends and pushes the blank through into the die cavity. Handling time should be carefully considered in estimations, since, due to the lack of any location, the material to be blanked must be sighted under the punch by the operator for each stroke. These tools, however, although eminently suited to very small batches are of little value where several thousands of components are required and of course have no place in mass production.

To meet the needs of large volume production the pierce and blank follow-on tool was introduced. The follow-on type is extensively used in batch work where it is usually hand fed. With certain modifications incorporated, the tool may be used for high speed auto feed work in mass production. A typical follow-on tool is shown in Fig. 18. It will be noticed that at Station 1 the two holes are pierced and at the following station these are engaged by the blanking punch, thus locating the strip just prior to blanking. At each stroke of the press then, one finished component is produced. The example shown is a comparatively inexpensive tool very suited to hand feed using either strip or coil.

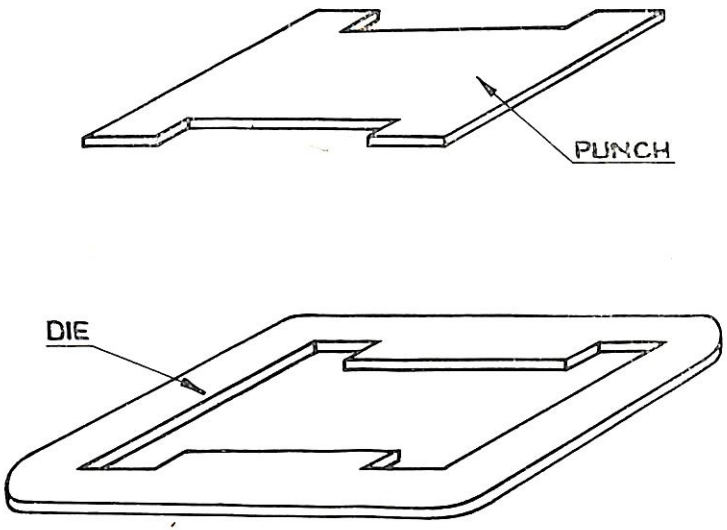


Fig. 17.

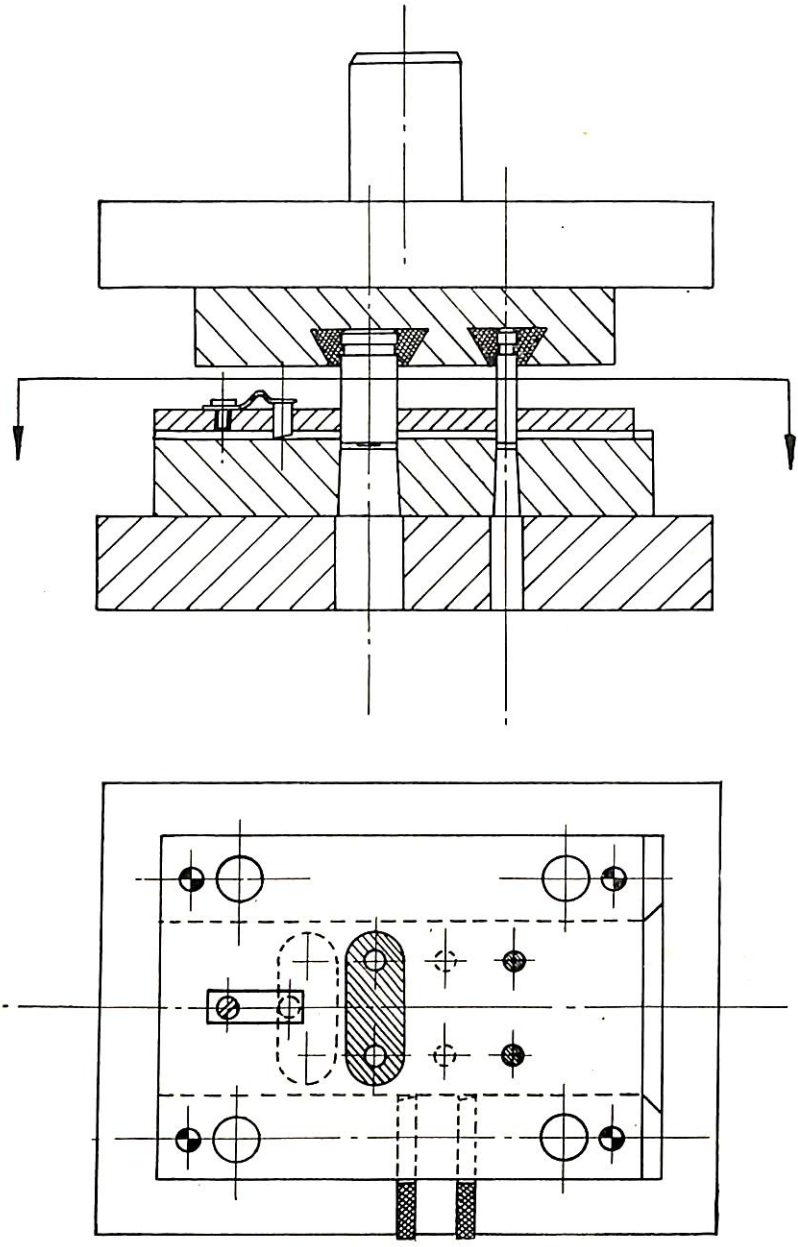


Fig. 18.

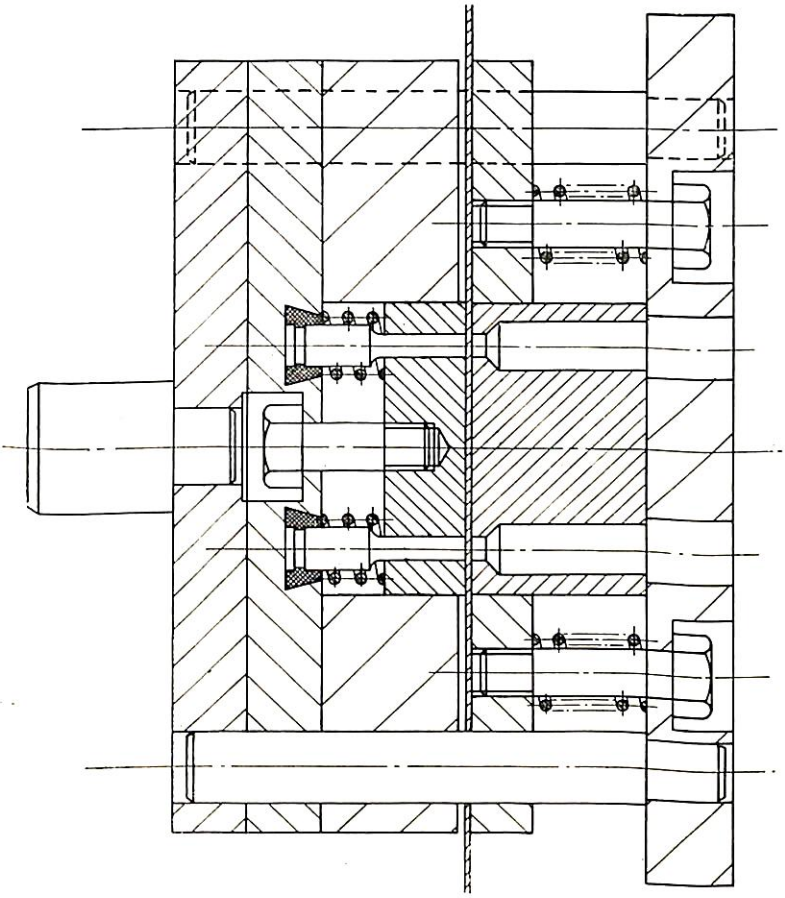
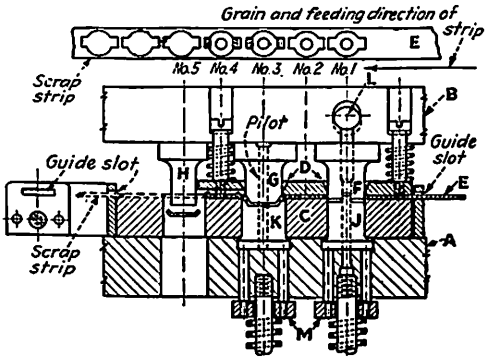


Fig. 19.



Hinman's "Pressworking of Metals."
By courtesy of McGraw Hill Book Co., Inc.

Fig. 20.

Fully automatic feed from coil stock is possible with the single stage pierce and blank tool, Fig. 19, which completes the entire operation at one stroke of the press. Here production time will depend principally upon the speed of the press itself. In applications of this sort in mass production the blank, as it is produced, is usually blown clear of the die by a jet of compressed air.

Compound progressive dies are elaborate tools for fully automatic high speed mass production work, being capable of performing several different and distinct operations and producing a finished component at every stroke. Such a tool, suitable for gauges up to about ·062 ins. thick, is shown in Fig. 20, together with a diagram of the scrap strip.

A and B are the die and punch holder respectively ; C the die itself ; D is a spring stripper plate attached to B ; E is the material being blanked ; F is the blanking punch ; G is the forming punch which carries a locating pin ; H is a punch which pushes the finished piece out of the strip, and J and K are respectively spring loaded ejecting and forming shedders.

The strip is blanked and pierced at Station 1, slugs being pierced by the stationary punch situated within the sliding ejector J. These slugs pile up inside punch F and finally fall out through the sloping hole L. Spring plates M, compress the shedders J and K and upon the ascent of the ram push the cut blanks back into the strip before the stripper plate relieves its pressure on the strip.

Stations 2 and 4 are idle and the blank rides over these whilst being held in the strip. Idle stations provide needed space for mounting the punches and, by virtue of the extra mass of material so obtained, permit greater strength in both punch holder and die.

The blank is relocated by the pilot in punch G and then formed by this same punch as it descends onto the shedder K. After the

work passes beyond G a clearance channel cut in the stripper plate permits the passing of the formed-up wings on the piece in the strip.

At Station 5 the piece is merely pushed out of the strip by punch H and drops through clearance holes in the die and press bed into a suitable container below.

The deep drawing of metals is a specialised branch of press work and it is impossible to cover deep drawing die design adequately here.

However, the principle of drawing a simple cup is indicated in Fig. 21. As the press ram descends the pressure pad grips the flange of the cup and the punch pushes the remainder of the material into the die, thus forming a cup shaped article. The pressure pad does not act as a positive clamp but is arranged so that some of the material will "flow" from the flange into the walls of the cup.

Deep drawing often necessitates several drawing operations interspaced with suitable heat treatment. Precise planning in many cases is impossible since the exact behaviour of the metal under the dies cannot always be anticipated with any degree of exactitude. More will be said about deep drawing later in the chapter.

Determining the Blank Size.

Component drawings rarely give information regarding blank sizes and a little simple arithmetic is usually necessary to obtain these sizes. The process planner must know the developed shape of a component for several reasons. As will be explained later the blank size determines the most economical arrangement of blanks in the strip and also the actual width of the strip; two important considerations. Also, by computing the area of the developed blank and knowing the gauge and the material that is to be used, an approximation of the press tonnage required can be obtained.

Fig. 22 (*a*) shows a section through a formed detail. This may be redrawn as at (*b*) showing *inside* dimensions of the bend and the position of the "bend line." When the inside radius of a bend is greater than twice the gauge thickness of the material the bend line may be taken as central in the strip, *i.e.*,

$$\text{bend radius, R} = \text{inside radius} + \frac{T}{2}$$

where T = thickness of the strip.

Where the inside radius is equal to or less than twice the gauge thickness, then,

$$\text{bend radius, R} = \text{inside radius} + \frac{T}{3}$$

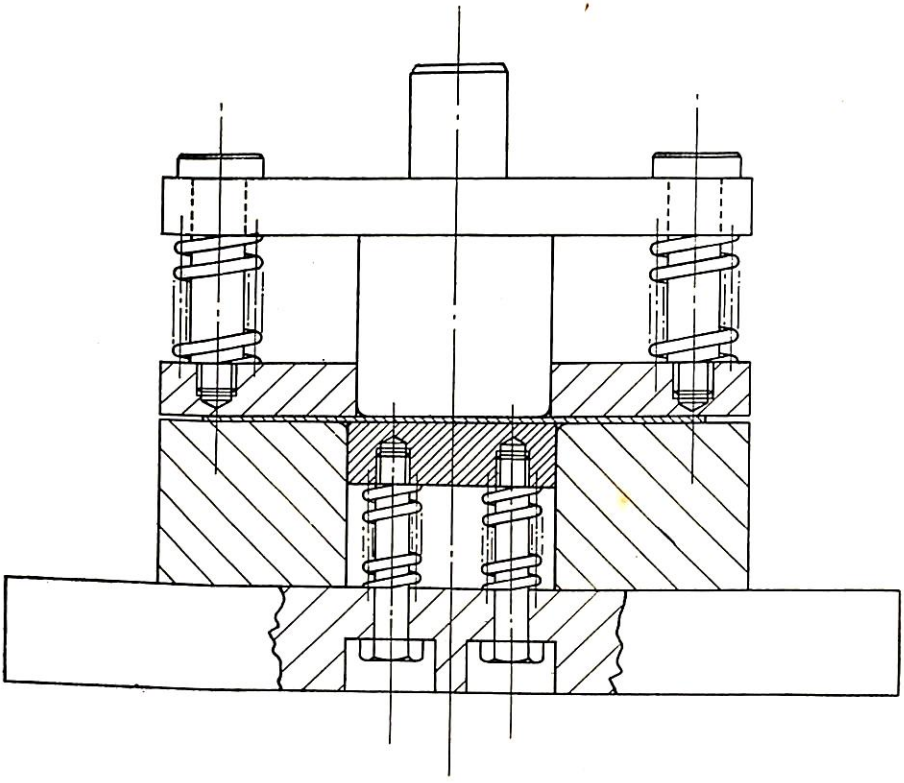


Fig. 21.

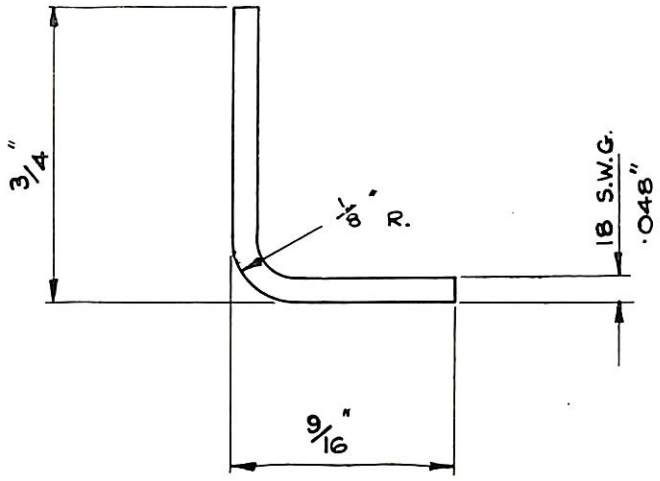


Fig. 22a.

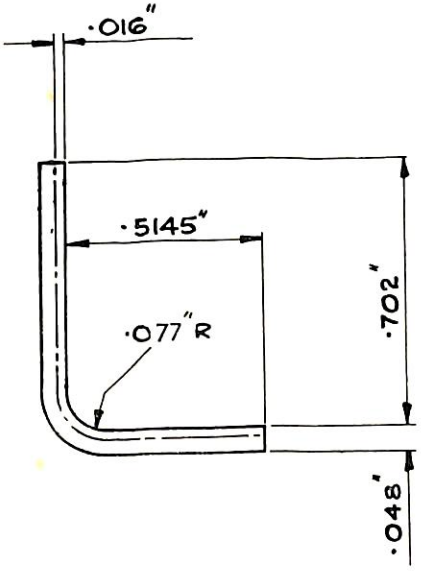


Fig. 22b.

This is true for thin materials but for medium gauges the bend radius depends upon the natural thinning which occurs at the bends and upon the temper of the material. Typical values are :—

Aluminium (up to half-hard) soft brass and copper ·35T
Aluminium (hard) half-hard brass and copper and soft steel .... ·40T
Hard rolled brass, copper and steel ... ... ·45T

Use of these values will give blanks to within about ±·020 ins. Finer tolerances can only be obtained by trial.

For cupping and deep drawing,

$$\text{Blank diameter, } D = \sqrt{d^2 + 4dh}$$

where d = inside cup diameter.
h = inside height.

For irregular drawn shapes, compute total elements using this latter formula and then apply :

$$\text{Total blank diameter, } D_1 = A \times 1{\cdot}272$$

where A = total area (comprising blank diameters of all individual elements).

Blank Layout.

If maximum economy of material is to be obtained it is essential that the position of the blanks on the strip be planned for the most favourable condition. Sometimes there can be only one arrangement due to the peculiar shape of the blank but usually savings of between 5% and 20% are possible on a well designed strip layout.

Fig. 23 shows a typical blank ; an electrical transformer lamina. The blank layout is elementary and wasteful and that shown in Fig. 24 is better, despite the fact that the strip is wider. The optimum arrangement is indicated in Fig. 25.

An allowance must be made at the edges of the strip and also between adjacent blanks to ensure a good finish on the product and for the effective operation of the press. The following table gives suitable allowances for the bridges between blanks.

Inches

Thickness of strip	·010	·020	·030	·040	·050	·060	·070	·080	·090	·1
Bridge width	·020	·025	·030	·035	·040	·045	·050	·055	·060	·065

The allowances to provide at the edges of the strip should be wider than these figures and in considering edge allowances the type of material should also be taken into account. The following gives suitable allowances in this respect.

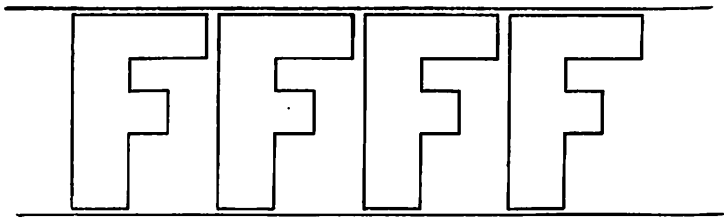


Fig. 23.

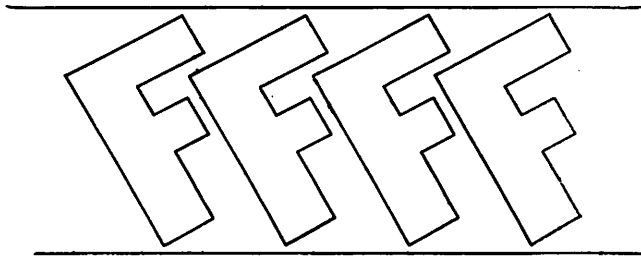


Fig. 24.

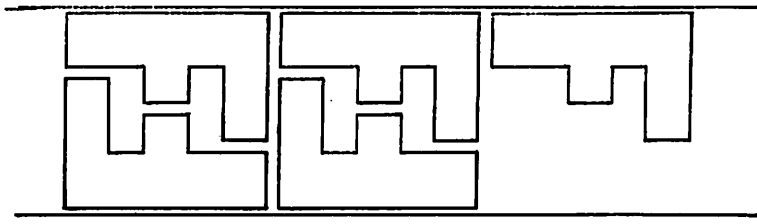


Fig. 25.

Blank dia. in inches	Edge allowance in inches	
	Aluminium up to ·020 in. thick	Aluminium over ·020 in. thick and brass, copper and steel
Up to 1½	⅛ - 3/16	⅛
1½ - 3	¼	3/16
3 - 5	5/16	¼
over 5	½	⅜

As a further economy in material, it is good practice to keep a record of the approximate size and quantity of piercings and scrap from previous components, that may possibly be utilized for blanking or cropping, during the manufacture of other piece parts.

Blanking Pressures.

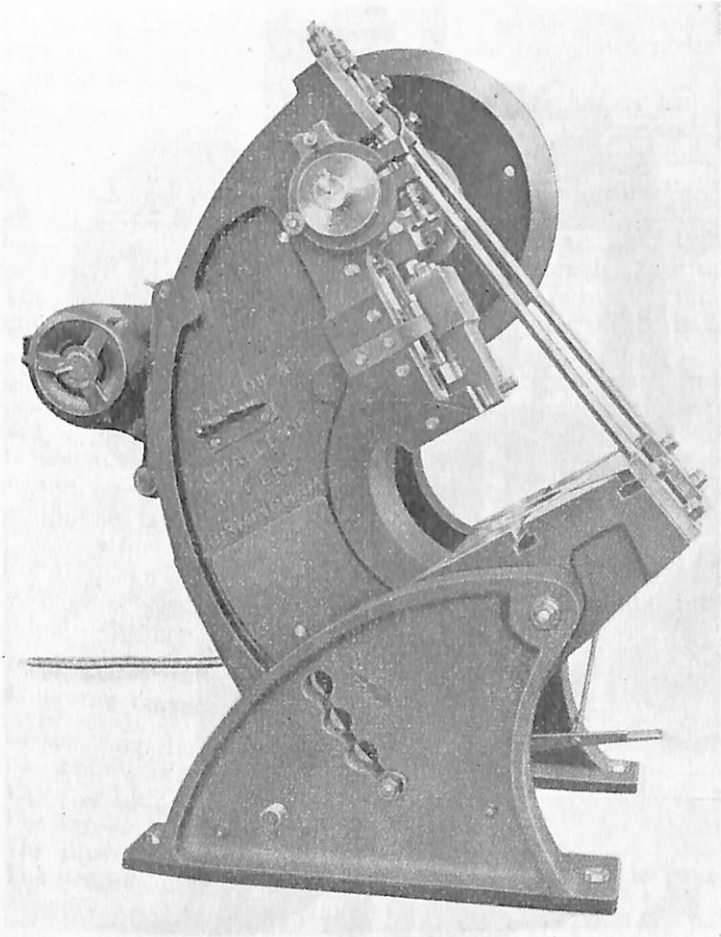
The total pressure required to blank a given piece from the strip is a function of the shear strength of the material being used, its thickness and the length of periphery of the blank. Tables 13 and 14 in the Appendix provide all information.

Press Types in General Use.

Press design varies considerably and accurate classification is correspondingly difficult. Nevertheless two main types are distinguishable, namely, the Gap Frame, Fig. 26, and the Straight (or Double) Sided, Fig. 27.

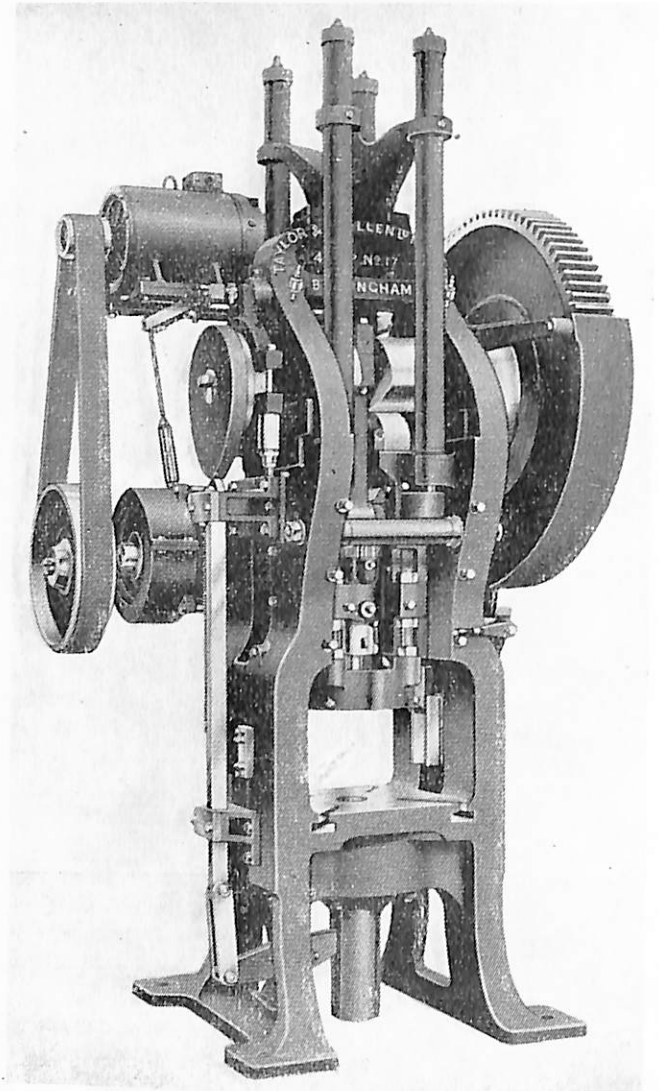
The gap frame press, so called because of the open sided nature of the frame, is available in a wide range of capacities. The smallest types, designed for bench work, are available within the 1 - 12 tons capacity range, the inclinable types within a 4 - 90 tons range and a capacity of anything from 100 tons to 2,000 tons and over is usual in the open back type gap presses.

Bench presses are used for light assembly and small press work generally and most of the automatic feeding mechanisms and other attachments are available for use in conjunction with them. The inclinable press is perhaps the most significant type in the gap frame class and may be used for the majority of requirements for single action and combination die work on small articles in light sheet or strip. Use includes blanking, forming, bending, light stamping, assembly and even drawing, where attachments are fitted. The inclination of the press bed facilitate the rapid ejection by gravity, of certain classes of components.



By courtesy of Taylor & Challen, Ltd., Birmingham.

Fig. 26.



By courtesy of Taylor & Challen, Ltd., Birmingham.

Fig. 27.

Large work which demands the use of two operators may be adequately handled by the open back type of gap press. This machine is also useful where material must be fed from the front to back of the press instead of the usual right to left motion.

For really heavy work on large sheets the gap frame design is unsuitable due to the frame itself having a tendency to spring under load, yielding an inferior product and in some cases leading to fracture of the press frame. To overcome these difficulties the straight sided press is used.

The straight sided construction consists of a press bed, two uprights and a crown. Built either plain or geared and with simple double or triple connection between ram and shaft, the design is capable of the heaviest work.

Machines of this type, like the open back gap frame press, must be fed from front to rear. The arch press, the smallest type, is suited to light press work on large sheets with a single operator.

The double crank machines, of which there are over a hundred standard sizes available, is made in capacities up to about 2,000 tons.

For very large sheets requiring four operators such as are used for drawing automobile body parts, the four point suspension press is used, available in 2,000 tons capacity and upwards.

It will be appreciated that many types of specialised presses exist, too numerous to mention, such as high speed and double action presses and hydraulically actuated machines with special long strokes for deep drawing, etc.

For the sake of completeness mention is made of the hand fly press or arbor press, although this, like other small hand presses, is undoubtedly familiar to the majority of engineers.

Selecting the Correct Press.

In selecting the correct press for any given job the following points should receive careful consideration :—

The size and type of die to be used.

The stroke necessary.

The pressure required for the operation.

The distance above the bottom of the stroke where the pressure first occurs.

Any additional pressure required due to attachments or for ironing wrinkles or for stretching material in drawn work, etc.

Method of feeding and the direction of feed.

Size of the sheet or blank or, in the case of an assembly, the size of the actual components.

When the pressure occurs at or near the bottom of the stroke and the stroke required is comparatively short, Table 15 may be used. It is assumed that the diameter of the crankshaft of the

press that it is intended to use is known or that this information is available.

Where the pressure occurs at a distance above the bottom of the stroke or where, as in deep drawing, the length of the stroke is fairly long, the load on the crankpin produces an appreciable torsional load on the crankshaft.

On some single crank presses with a very long stroke or on double crank presses of great width and on all long single and double crank presses a gear is provided on each end of the crankshaft and this arrangement increases the gearing strength and the torsional capacity of the crankshaft but the theoretical load is not always readily calculated.

However the load at the *bottom* of the stroke is easily obtained since in nearly all presses it is governed by the figures given in Table 15. When in this bottom position the crankshaft may be likened to a beam supported at both ends with a concentrated load at the centre.

In cases of doubt the advice of the press manufacturers themselves should be sought.

Handling Times in the Press Shop.

Handling, whether it be on small or large components, is a major consideration in any press shop; the time for the actual operation of the press itself being secondary.

The constituents are invariably :—

Clean (and grease if deep drawing).
Insert in die.
Actuate press.
Eject or remove.
Dispose of scrap.

On small presses the stroke is so rapid that handling practically governs the rate of production. The process planner should be conscious of this fact and provide automatic feed where quantities warrant the installation, or he should consider the advantages, if any, of roll feed over separate strips.

Lengths of strips, where used, should be called for to be from four to six feet in length to make for ease of handling, and they should be placed within easy reach of the operator by a labourer or the materials handling department, etc. The operator himself should never be required to cut his own strips and transport these to his press.

On larger work the picking up of a new piece ready for insertion can often be completed, or nearly so, while the press ram is moving.

Some constituents are given in Table 16 and this together with Table 17 giving number of strokes per minute that may be expected

from various sizes of presses, should assist in arriving at a reasonably accurate floor to floor time for planning and estimating purposes.

Remember, however, handling time is always the major factor and constant attention should be given this.

Deep Drawing.

Bending, raising or folding (all three terms are used for the same process) consumes about half the power needed for drawing and the pressure on a drawing punch is approximately similar to that required for blanking out the bottom of the formed cup. These statements are true for nearly all drawing work and may be used when deciding upon the allocation of a press, except in the case of a component where severe extending or ironing action occurs.

Drawing presses in common use vary in their speeds from 3 to about 30 strokes per minute according to their designed power and length of stroke. The exact figure must be found by consultation with the makers before accurate production estimates can be made.

Handling in deep drawing operations is dependant upon a variety of conditions and accurate forecasting cannot always be made. Ejection is often automatic and need not be time consuming. Loading may be anything from three seconds upwards depending upon the size and complexity of the component and its locations.

Constituents and contingencies are similar to blanking but with the addition of time for tool attention. Deep drawing is a severe operation and the drawing punch must be given periodical stoning and polishing if pick-up and scoring of the work is to be avoided.

As already noted, several successive draws are usually needed for all but the shallowest of cups, and these will involve additional handling and fatigue allowances.

Annealing must not be overlooked since heat treatment is usually necessary between each drawing operation.

The deep drawing of cylindrical shells is governed approximately by the following rules :—

In single action drawing allow reductions in diameter of 25% for the first and second draw (30% is sometimes permissible) and 20% for the third and later draws with heavy gauge material, *i.e.*, over $\frac{1}{8}$ in. thick. Allow 25%, 20%, 15% and 10% for gauges thinner than $\frac{1}{8}$ in.

In double action drawing allow reductions of 40% for first, $33\frac{1}{3}$% for the second, and 25% for the third and later draws, with thick material. With light gauge stock reduce $33\frac{1}{3}$%, 25%, 20%, 15% and 10% respectively.

CHAPTER VII.

MATERIALS HANDLING.

Every time a material is handled something is added to its cost but nothing to its value. Just how much money is spent every year in handling materials within a works is not always realised, even by top management. The exact expenditure incurred is often never shown in accountants' figures since handling is usually not costed as a functional process but rather as a factory oncost. By taking a cross section of the industry it may be proved that between 15% and 85% of the manufacturing cost of an article is accounted for by handling alone. Sometimes as much as 15 tons of material is moved in order to produce 1 ton of product. The economy potential here awaiting tapping is obvious and many firms are now tackling their handling problems in a very realistic manner.

Materials handling may be defined as the movement, mechanical or otherwise, of everything within an establishment. It includes the handling of raw materials and tools, the movement of components between one operation and the next, the handling of scrap, swarf, and cutting oils, and the final movement of the finished product from stores or assembly line through packing to despatch deck.

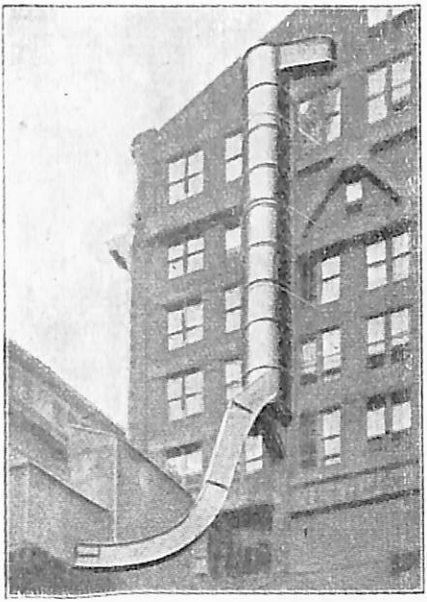
This handling of materials if it is to be efficient must be carefully planned with the same skill as is usually bestowed upon operation planning. Handling then becomes a matter of some significance and worthy of the technical interest of the process planner for efficient handling is indeed an important factory process.

Gravity Chutes.

Gravity chutes are one of the simplest types of conveyance, cheap and simple to install and with negligible maintenance costs. Fig. 28 shows an enclosed spiral chute erected outside a multi-storey building with connections to all floors. An entirely different application is shown in Fig. 29. Here the handling of components from a broaching machine to the next operation is effected speedily and smoothly using a simple trough type chute.

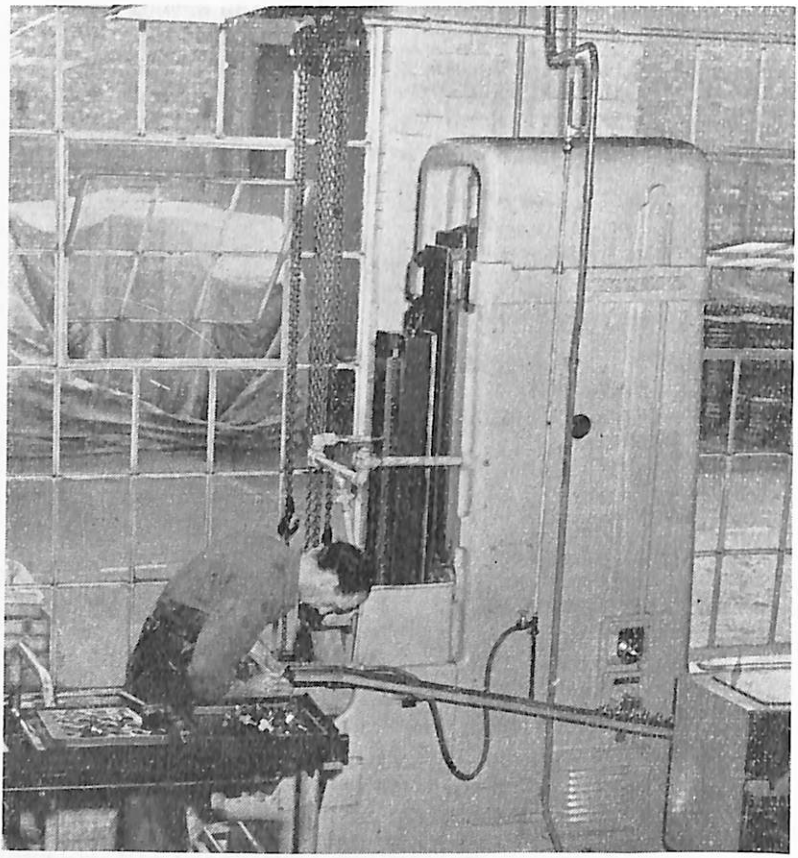
Conveyors.

Conveyors are of two types, gravity and mechanical. Perhaps one of the most familiar type of gravity conveyors is the roller track, Fig. 30. This design is very adaptable, it being possible to incorporate switch points and turntables in the track and the



Koshkin's "Modern Materials Handling."
By courtesy of John Wiley & Sons, Inc., New York.

Fig. 28.



By courtesy of F. Perkins, Ltd., Peterborough.

Fig. 29.

fitting of hinged sections for clearing gangways, etc. It is efficient and requires little or no maintenance. By tapering the rollers in the necessary direction material may be directed around bends and between machines. A 3% - 5% gradient, depending upon the weight of the material, is ample for most types of work. Braking, if necessary, is effected by fixed rollers or by the provision of magnets beneath the track.

Mechanical type conveyors are available in many different forms to suit almost every purpose. The familiar belt conveyor for light assembly work is shown in Fig. 31. For medium work the slat conveyor, Fig. 32, is used, and for heavy assembly the double chain open type is often employed, Fig. 33. All these systems operate on the principle of an endless belt or chain running over drums or sprockets at either end of the line and driven by an electric motor. A tensioning device is included and speed is infinitely variable by means of suitable motor control gear.

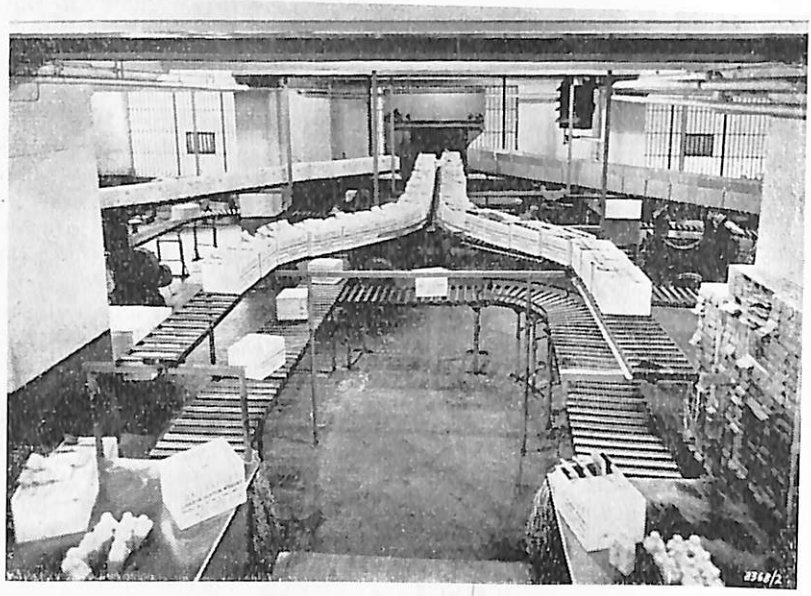
The system, although eminently suited to assembly work, may be similarly employed to convey any sort of material in any form from one department to another by fitting suitable containers such as metal boxes, wire crates, sand hoppers, etc., at intervals along the belt or chain.

The overhead conveyor is similar in principle to the last mentioned consisting again of an endless chain driven by an electric motor. Its main use is the transport of material, Fig. 34, but it is also used as a moving reservoir or "storage area" for material and occasionally for assembly purposes. As a reservoir of material it may be arranged to run in the span of a saw tooth roof, clear of supply pipes and cables, etc., and utilizing space that would probably be otherwise wasted. An overhead conveyor from stores to, say, assembly area need not necessarily follow the shortest route ; indeed in many cases the run is purposely made considerably longer than necessary so that material may be stored on the conveyor instead of using needed space in the stores area itself. Consider a conveyor carrying 500 loading points having a capacity of $2' \times 2' \times 1\frac{1}{2}'$ high. The storage area here is $500' \times 2' \times 2' \times 1\frac{1}{2}'$ or 3,000 cubic feet—a worthwhile facility in any works.

Press Elevators.

The segregation of scrap from usable blanks and the disposal of both these commodities is a problem in any size of press shop.

Full conveyorisation is justifiable in larger undertakings but such a step would probably not prove economic in a small shop. Mechanised press elevators, however, are worthy of consideration. These self-contained units are designed to pick up scrap from under the press bed and convey it upwards to a stillage or other receptacle for subsequent removal to the scrap disposal point, Fig. 35.



By courtesy of Paterson Hughes Engineering Co., Ltd., London.

Fig. 30.

By courtesy of Fisher & Ludlow, Ltd., Birmingham.

Fig. 31.

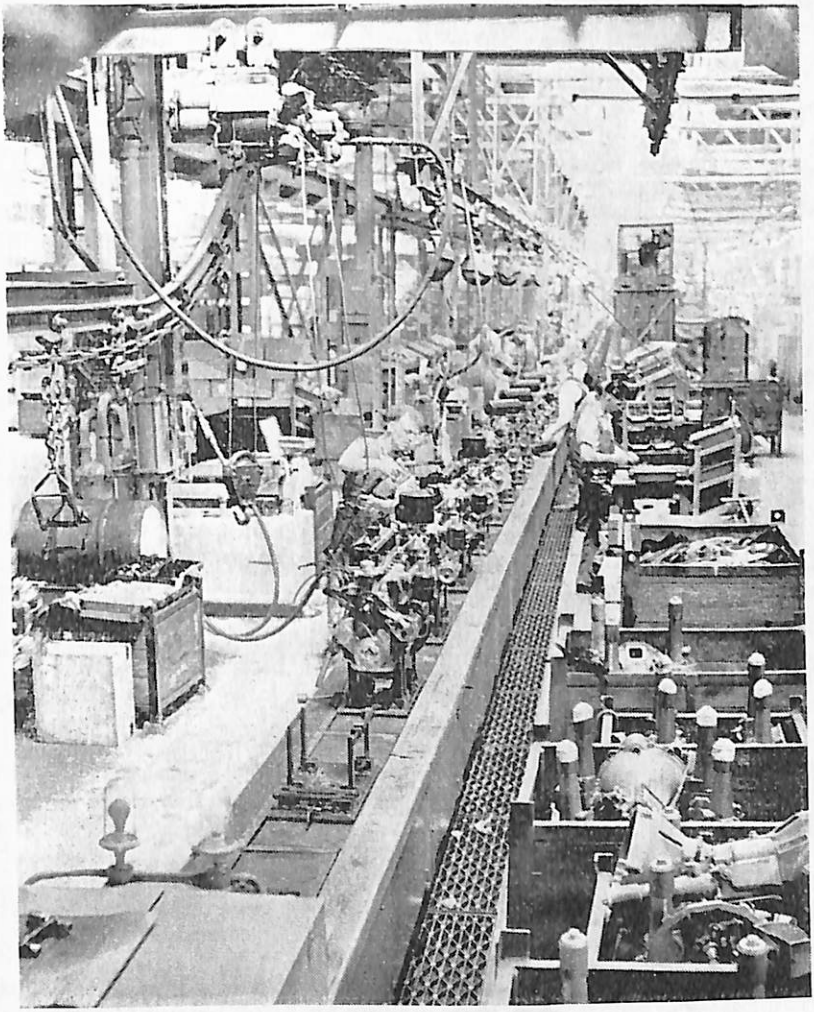
Pallets and Fork Lift Trucks.

In all methods of handling, be it mechanical or otherwise, it is often necessary to pack material into containers prior to transit. Suppose raw material is being issued to the machine shop and handled through the various operations to the finished part stores. During its journey the material will change its shape, weight and form quite considerably. In old fashioned handling methods small rough castings might be delivered to the machine shop from the stores in a sack by means of a hand barrow or flat platform truck. After the first machining operation the sack would probably be discarded for a more suitable container. One or more wooden or metal boxes might be used, probably of different sizes. As the machining of the component progressed care might be necessary to ensure against accidental damage. Components may now need a special shaped box or be laid in paper or felt. An immense amount of packing and unpacking is required by this haphazard method involving much waste of time and labour as well as inviting errors, loss, pilferage and accidental damage.

Palletization aims at delivering raw material in one or other of the standard unit loads by means of a fork lift truck, conveying the material in similar units throughout its progress in the works and finally stacking it in the stores still retaining the shape of a standard unit.

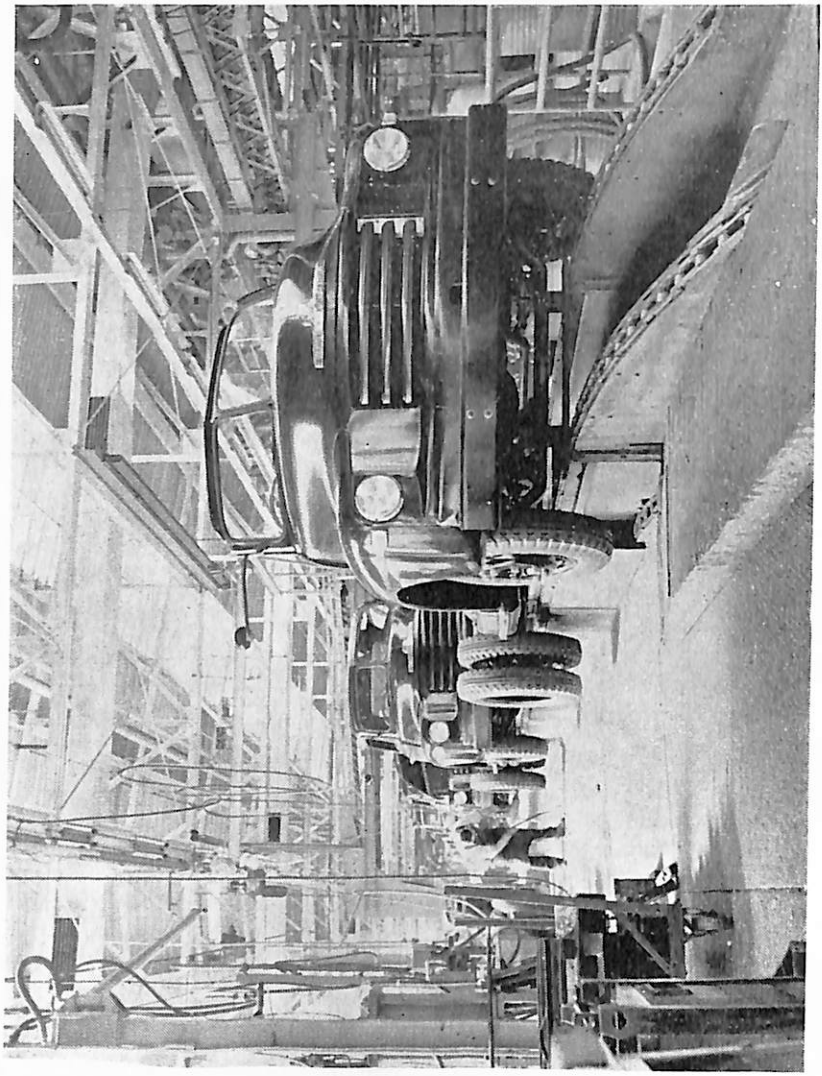
There are several forms of pallets; some of the more usual are shown in Fig. 36. It will be noticed that except for the flat type pallet all are fitted with "nesting" feet so that they may be placed one on top of the other by means of a fork truck. Special pallet trucks may be used to move individual pallets but for stacking purposes a fork lift truck is essential.

The mechanical handling industry boasts an extensive range of fork lift trucks operated either electrically or by petrol or diesel engines and offering these types in various capacities of load and elevation. Some makers use a chain and gear system for raising the forks, in others this latter is hydraulically operated. In most models the mast is telescopic. This feature ensures a high lift, as much as 20 ft. in some cases, whilst at the same time the truck is able to pass beneath a normal factory doorway. Fig. 37 shows three representative types. At (*a*) is the Lansing-Bagnall pedestrian controlled fork truck. This little vehicle is capable of raising a maximum load of 1 ton to a height of 5 ft. 7 ins. in one lift or 10 ft. 10 ins. using the telescopic lift. A valuable feature is that it may be operated in aisles as narrow as four feet. An equally popular vehicle but in the medium capacity class is the Stacatruc 3-tonner shown at (*b*), with a maximum fork lift of 14 ft., available petrol or diesel powered. This truck requires a minimum aisle width of about 5 feet but for right angle stacking this should be increased to 12 ft. 6 ins. For really heavy work the Shelvoke



By courtesy of Vauxhall Motors, Ltd., Luton.

Fig. 32.



By courtesy of Vauxhall Motors, Ltd., Luton.

Fig. 33.

and Drewry "Freightlifter" (*c*) offers 8 tons carrying capacity with a 20 ft. maximum lift. Although designed for arduous duty the truck is by no means unwieldy having a turning circle of only 14ft. 3 ins. and being capable of traversing an aisle of as little as 8 ft. wide.

Scrap and Swarf Disposal.

Reference has already been made to press elevators. The automatic screw machine shop is another department where large quantities of swarf must necessarily be disposed of. In this case a further complication is present in that not only must different materials be kept separated from one another but the swarf itself is usually heavily laden with oil.

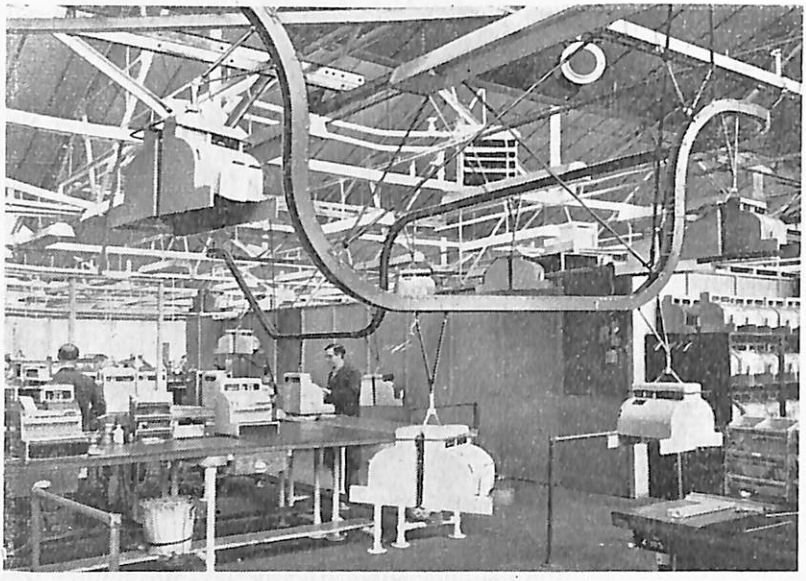
To merely scrape the swarf out of the machine into a wheelbarrow and thence tip it onto a dump is wasteful indeed. Not only must the swarf be again shovelled by hand on to a lorry but much otherwise recoverable cutting oil is lost. Approximately 100 gallons of oil is usually recoverable from a little more than a ton of average steel swarf.

A simple bucket type conveyer system might be installed to transport swarf from the automatic shop direct to the swarf house or a fork truck could be used in conjunction with a special oil tight box pallet. Once inside the swarf house the material may be separated from the oil by means of a mechanical centrifuge, if quantities warrant the installation of such a machine, or merely left to drain. In either case the recovered oil should be purified and returned to the auto shop for re-use.

Planning a Materials Handling System.

Planning a materials handling system will depend, as in all other forms of process planning, upon the method of manufacture carried on in the works under consideration and also upon a consideration of the quantities and types of product it is required to handle.

In the small jobbing shop the amount of material to be moved at any one time may be small but it must be borne in mind that it may be heavy or cumbersome and involve much labour even if only for a limited period. In such establishments it is not uncommon for instance to find a skilled universal milling machine operator lifting a large machine vice from the floor or an adjacent shelf either by himself or with the temporary assistance of a colleague. In another section of the workshop a skilled turner might be seen mounting a heavy faceplate on to his lathe without any aid whatsoever save for a chock of wood to lever the plate into position. Skilled labour is expensive indeed to use on a purely labouring job.



By courtesy of Geo. W. King, Ltd., Stevenage.

Fig. 34.

By courtesy of Fisher & Ludlow, Ltd., Birmingham.

Fig. 35.

Again, it may be noticed in some shops that material in process is handled from operation to operation in any wooden or cardboard container that happens to be at hand. Naturally, by these methods, delay is sometimes occasioned by the complete absence of a suitable container at the time it is required.

It is an economic possibility in many small concerns to introduce several inexpensive mechanical aids to handling. A mobile hydraulic jack with flat platform will speedily raise a machine vice or large press tool to the required level from whence it may be merely slid off the jack into position. An electric hoist arranged to run in an overhead monorail would be a useful adjunct in many cases or a portable crane may serve a similar purpose if placed in the shop and made available to all.

Almost too obvious to mention is that metal work boxes, or tote boxes to give them their modern name, should be made available in sufficient quantities and of the correct size for the conveyance of all work in progress. Several specialist firms undertake to supply these articles together with suitable metal racks for stacking purposes.

Naturally, there are limitations to the use of much complex handling equipment in the small type of factory but it is certain that some improvement, no matter how small, can be made somewhere in the manufacturing set-up.

Handling in a batch or mass production plant can be an extremely complex business and the original installation design will demand all the technical resources of the average process planning department.

Suppose it is required to introduce a comprehensive handling system in a works where material has hitherto been moved by means of outdated methods. From the various operation layouts it will be possible to chart material flows. Now palletization and the use of fork trucks are undoubtedly of considerable value, but these should not be considered until all the possibilities offered by the use of the many types of gravity and mechanised conveyers have been thoroughly explored. A fork truck requires an operator and attendant maintenance. A safe rule is to conveyorize whereever possible as a first step, always, of course, provided it is justifiable to do so, and then introduce the fork truck only where it is absolutely essential.

Having decided with reference to the flow charts what material is to be conveyorised it only remains to plan for the introduction of palletization. The first step to make is a detailed study of all gangways, doorways, outside roadways and overhead obstructions such as gantries, pipes, power cables and the like.

Gangways that are intended to take fork truck traffic need to be comparatively wide and right angle corners must be of suitably

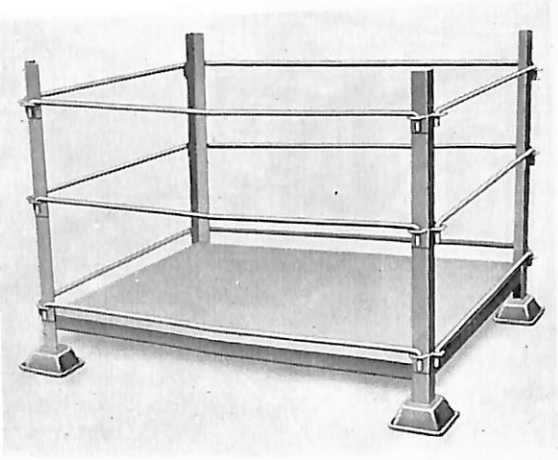


Fig. 36a.

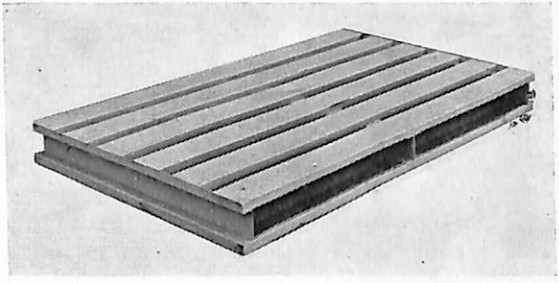


Fig. 36b.

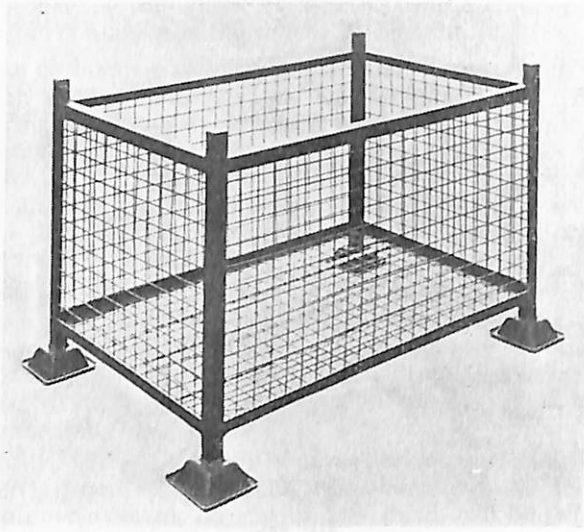
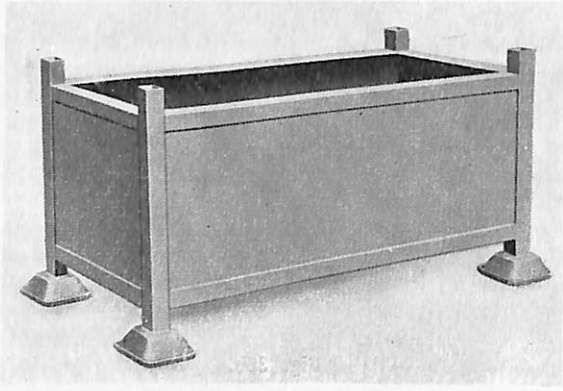


Fig. 36c.



By courtesy of Rubery Owen & Co., Ltd, Wrexham.

Fig. 36d.

generous dimensions. The various manufacturers of fork trucks will supply relevant information in this respect.

Doorways must be examined for suitable width and height. Structural alteration here is not usually difficult should it be found that some entrances are of insufficient proportions. The fork truck driver should not need to dismount from his vehicle in order to open and close doors and accordingly the latter should be automatically controlled by means of a photo electric cell and relay or the existing doors replaced by the all rubber variety.

Outside roadways should be examined for conditions of surface and extent of camber. Most fork trucks are available with a choice of tyre equipment, either solid, pneumatic or low pressure balloon to meet variations in running surfaces. Advice from manufacturers should be sought with regard to maximum permissible camber angle. It may be found that the condition of surfaces in some cases may have to be improved. If a fleet of vehicles is to be operated and internal roadways are narrow and difficult to negotiate it may be necessary to plan a one-way system of traffic control or install some form of traffic signal at obvious points of congestion.

Before deciding upon the size and type of fork truck to use, decide upon the most suitable size and type of pallet. The effective solution to this problem will depend upon the nature, shape and weight of the product to be handled, the usual batch size produced at any one time, the available height in the storeroom for stacking, the size and capacity of lifts in the case of multi-storey buildings and the available space around machines and assembly areas.

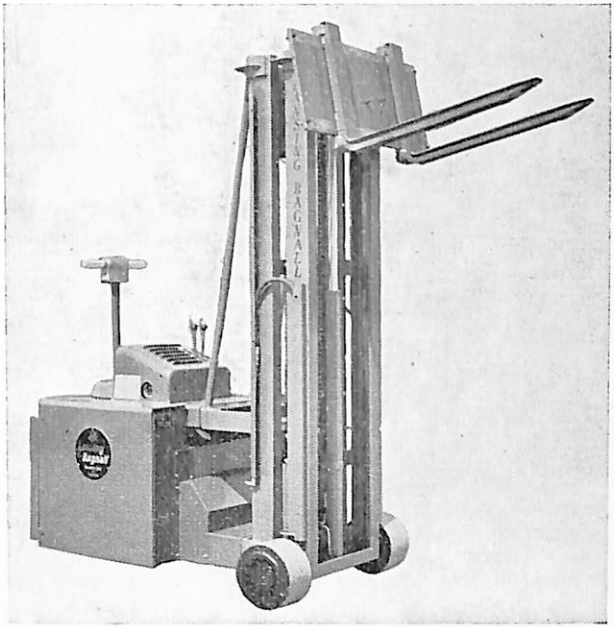
Pallets should be standard design wherever possible, although special pallets will be required occasionally to handle special jobs. The number of different types should, of course, be kept to a minimum and every effort made to avoid special pallets being used at different stages in the work flow.

When a decision has been reached as to the types and sizes of pallets that are to be used, their respective weights when fully laden should be calculated. Having arrived at these figures it is a simple matter to determine the weight of the heaviest loaded pallet that is likely to be handled. This latter figure plus a 25% safety factor will give an idea of the capacity of truck that will be needed.

It only remains now to choose the form of motive power the chosen truck is to have and this will depend upon local conditions at the factory. Obviously where the fire hazard is great or fumes are particularly objectionable an electric vehicle should be specified. A diesel powered vehicle is sometimes more economical to run than

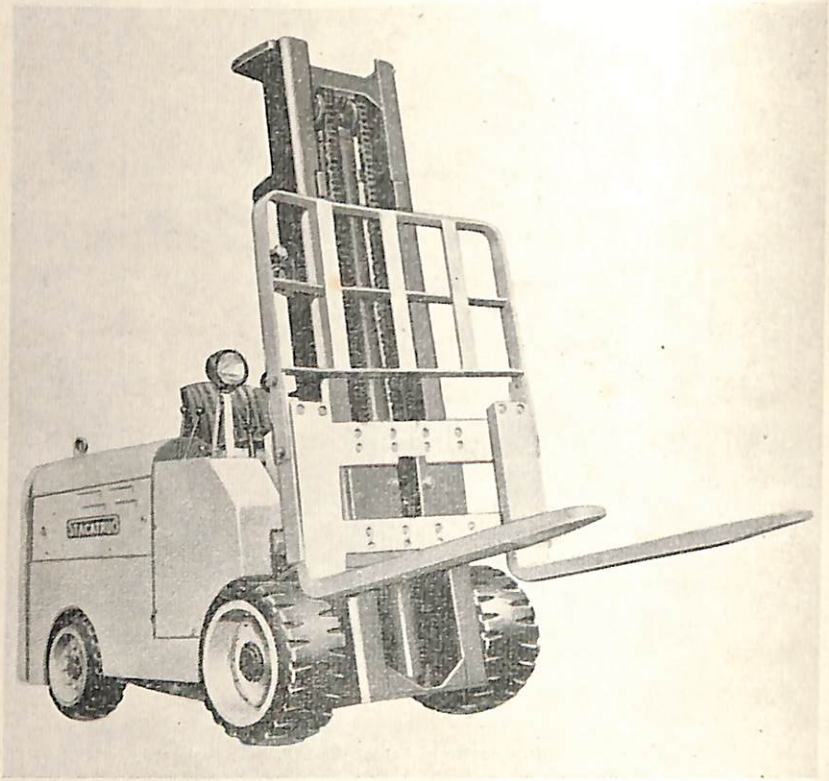
its petrol driven counterpart but first cost of the former is appreciably higher. As a rule it is better to specify a diesel truck only where loads are particularly heavy and hauls are unusually long. The petrol driven vehicle is the usual popular choice.

Finally it must be arranged that a sufficient number of pallets are always available to handle any sudden rush of work and a suitable system of maintenance of pallets introduced as an assurance against wear and tear since once a palletized system of handling is installed material can only be moved mechanically.



By courtesy of Lansing-Bagnall, Ltd., Basingstoke.

Fig. 37a.



By courtesy of I.T.D., Ltd., London.

Fig. 37b.

By courtesy of Shelvoke & Drewry, Ltd., Letchworth.

Fig. 37c.

CHAPTER VIII.

PLANT LAYOUT.

Before World War I manufacture in the metal working industries was, in many respects, a more leisurely business than it is to-day. Workshop personnel consisted mainly of skilled artisans and apprentices who maintained a jealous pride in their individual workmanship. Machine tools were regarded as almost adjuncts to the skilled hands of the craftsmen and it therefore mattered little where these were placed, provided they were sited conveniently to the work benches.

The positioning of plant in the workshop was usually the responsibility of the foreman, and upon the arrival of a new machine tool he made a decision on the spot where it should be placed. During the early 1900's it was the practice for power to be transmitted to machinery by means of a common overhead lineshaft and this feature in itself severely limited the choice of position.

As production facilities expanded it became apparent that a more systematic approach to workshop layout would help reduce the burden carried by supervision and speed up production. A change in outlook and methods was inevitable. The lineshaft gradually disappeared as machine tools became motorized. Constant development up to World War II, together with vast experience gained during that war saw plant layout brought to a level where it became accepted as a necessary, and indeed fundamental, function of efficient production planning.

Plant Layout and Management.

Plant layout is the planned arrangement of machinery and process equipment in an engineering works. It is the floor plan for ascertaining the correct type and quantity of machinery and equipment in order to permit the fastest possible flow of material with the least amount of handling right from raw material to finished product.

The plant layout, whether it be a scale model, a two dimensional plan or merely a working drawing, integrates factory land, buildings, departments, machine tools, processing equipment, manufacturing methods, materials handling, service facilities, utilization of labour, packing and despatching, in fact every operation within the factory into one huge "machine" of which management itself is the operator. It should thus be capable of presenting in graphic form the whole set-up necessary to turn out the planned volume of production within the bounds of the financial expenditure sanctioned by the management.

Plant Layout and the Planning Engineer.

From the foregoing it will be apparent that the planning of a plant, a new department or merely the re-equipping of an existing shop is something considerably more than the common conception of shuffling templates or scale models on a floor plan.

The process planning engineer, if called upon to undertake a plant layout appointment, must accept real responsibility, and when successful, may consider himself approaching the height of his professional status.

The remainder of this chapter, therefore, will outline the main points which should be considered when carrying through such a project.

The Basis for Layout Design.

From the original operation sheets, which it is assumed have been time studied, the process planner will be able to ascertain the weekly production obtainable, using the existing machinery and plant layout. Should the figure fall short of the required volume, replanning of the operations will be required in order to achieve the desired volume.

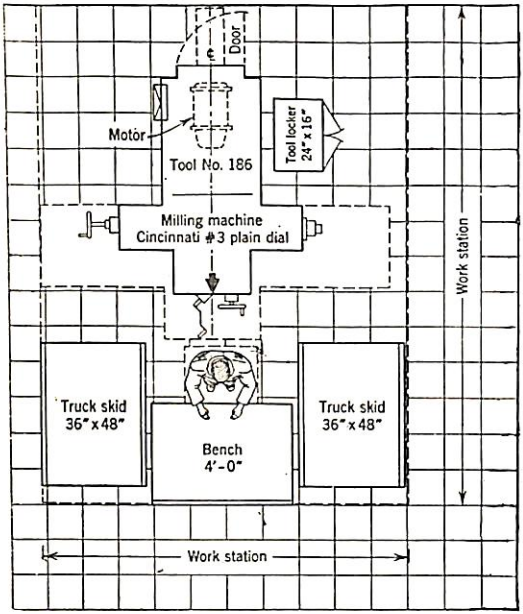
The nucleus, then, for a plant layout is the planned sequence of operations as laid down in the operation sheets together with the knowledge of the projected volume per week. With this information to hand the work of designing machine and processing locations, materials handling equipment and storage areas is commenced together with the charting of production flows, internal trucking routes, power supply lines and all other services. After finalizing the design the plant layout drawing or scale model is subsequently submitted to management for approval.

The Work Station.

The floor area occupied by the operator and the machine or group of machines he controls is designated the work place or work station. In layout design it constitutes the smallest indivisible space unit, a typical unit being shown in Fig. 38.

It will be seen that considerably more area has to be taken into account than merely that occupied by the actual operator and machine. Space must be allowed for the extreme position of the slides, etc., of the machine in both directions, any auxiliary equipment such as work bench or tool locker and ample allowance for the landing and taking up of pallets or stillages or for the provision of a conveyor track, depending upon the type of materials handling equipment it is planned to install at the particular station.

It is obvious that a work station be designed for the greatest motion economy, consequently, it may well be the case that two



By courtesy of Gaudreau Rimbach & Associates, Pittsburgh.

Fig. 38.

widely differing work station layouts may be designed around two identically similar machines simply because the operations performed on these machines are dissimilar.

The principle of the work station layout may be applied to assembly and other processes, but here the design may include several operators all jointly performing the same operation. The work station, however, will still preserve its distinctive identity as being an indivisible unit.

Assume now that work station layouts similar to Fig. 38 have been drawn out or are already in existence for every operation as laid down in the operation sheets whether it be machining, assembly, painting or any other process. The final plant layout will be an arrangement of all the work stations in a manner such as will obtain a regular flow of production with the least handling. This final arrangement, however, will depend quite considerably upon the method of manufacture since obviously a jobbing shop will need different handling technique from a mass production plant.

'Functional' and 'Flow Line' Plant Layouts.

Depending upon the method of production, two recognizable types of plant layout are in general use. What is known as the

'functional' type of layout is widely used in batch production industries whilst the mass production factories favour the 'flow line' type of layout. A combination layout consisting of both 'functional' and 'flow line' principles is also to be seen in many of the bigger concerns.

A flow line or, as it is sometimes called, a line production layout, is one where the necessary machinery of various types is placed along the line of travel followed by the flow of the piece part thus permitting each operation to be performed in close sequence. This permits work stations to be arranged in the order of operations, eliminates much handling of material from one operation to the next and facilitates the installation of chutes, conveyors and elevators, etc. In order to avoid bottlenecks the cycle time of each machine must be similar. Where this is not possible and the cycle time for a particular operation is longer than the others in the line, two or more similar machines must be installed so that their combined output will bring the cycle time for the slow operation up to the standard time of the line.

"Functional" processing disregards the product flow and groups all machines and equipment on a functional basis, *i.e.*, all capstan lathes in one department, all milling machines in another, and so on. This arrangement, as stated previously, is used in firms engaged in job or batch production since the sequence of operations here is constantly varying between one job or batch and the next and no line flow is possible. The arrangement, however, is also used as a feeder department to assembly lines in mass production, where the other departments within the organisation are laid out for flow line production.

The Use of Templates and Scale Models.

A few years prior to World War I progressive planning departments had already introduced the early block type template, Fig. 39. This shows a floor plan for a typical milling machine. It was soon made evident, however, that a more accurate form of template would prove of greater value and so the two dimensional template was introduced, Fig. 40. This showed the extreme positions of all slides, etc., and by its use a more definite approximation of machine location was obtained.

This method was in vogue right up to World War II when, with the tremendous increase in production that was demanded, the limitations of the system became realised. Many existing factories were faced with the problem of complete reorganisation in order to undertake the manufacture of war material where this differed considerably from their peaceful occupation.

Many entirely new factories were built and in every case machinery and production equipment were required to be installed with the least possible delay. It was at this time that planning

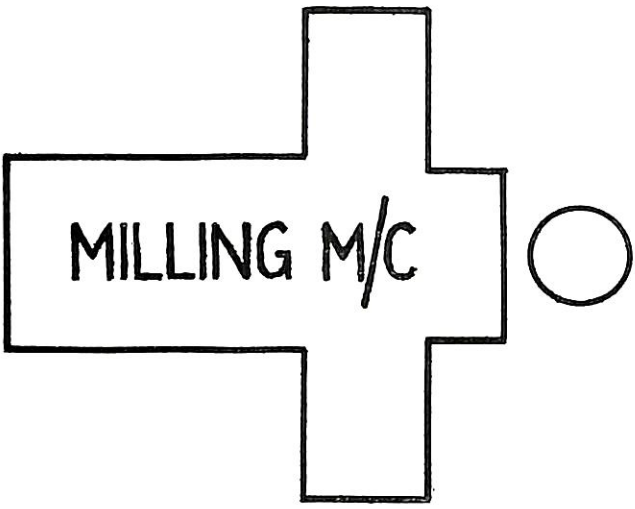


Fig. 39.

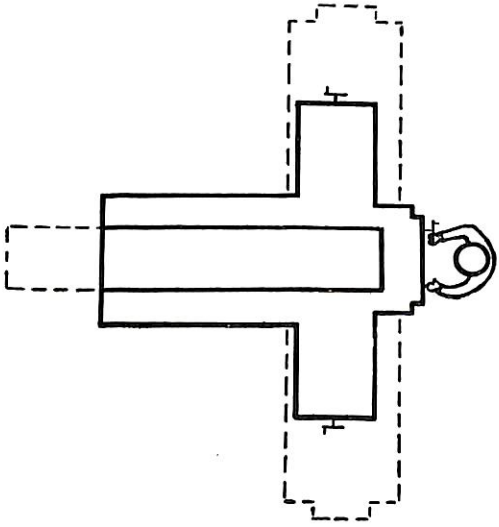
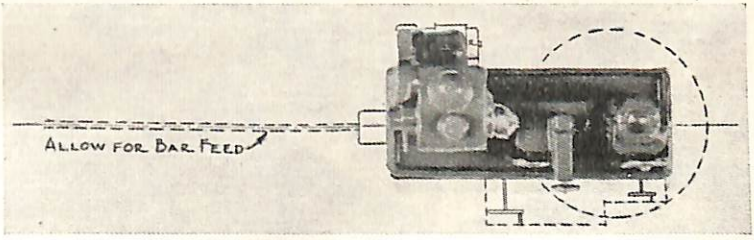


Fig. 40.

engineers found that in certain cases executives were none too familiar with the correct interpretation of layouts when presented to them in merely two dimensions, the system being more familiar to the draughtsman. Accordingly planning engineers began the work of constructing wooden scale models of all machines and equipment, usually to the scale of $\frac{1}{4}$ in. : 1 ft. Only a short length of time elapsed before these were replaced by proprietary metal models. With the introduction of scale models, plant layouts at once assumed a depth and reality unobtainable by using the template medium. What was even more important planning engineers discovered that it materially assisted them when visualising the functions of materials handling equipment especially overhead conveyors and swarf disposal media, etc.

Models alone, however, are not sufficient help in designing a proper layout since they do not indicate the traverse of slides, etc., on machines. Since the "miniature factory" will eventually have to be reduced to an engineering drawing for distribution before the actual work of shop reorganisation is commenced, it is of importance that the extreme position of these slides are in fact clearly indicated. The ideal, then, is the combination of scale model and two dimensional template. Fig. 41 shows a scale model lathe placed upon a two dimensional template.



Malevick & Gaudreau's "Plant Layout."

By courtesy of John Wiley and Son, Inc. New York.

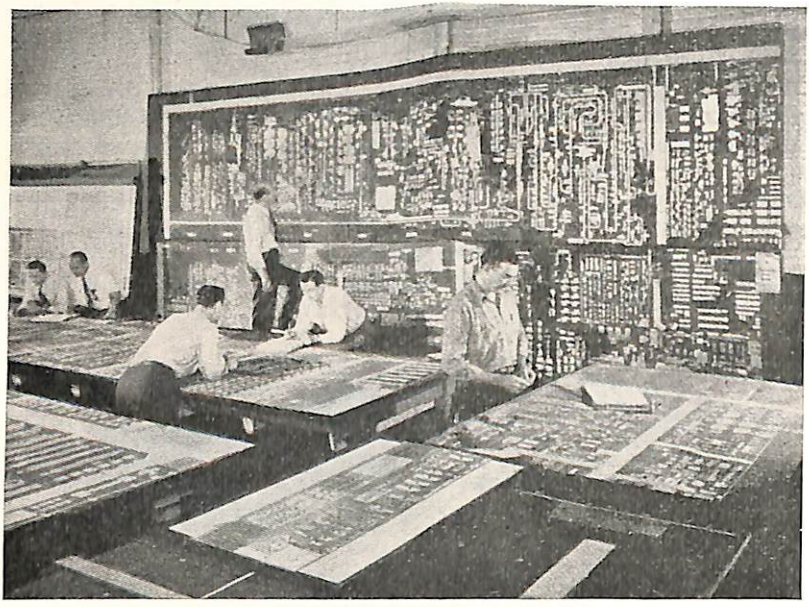
Fig. 41.

When the layout is finalized the models are removed and the templates secured to the floor plan by glue or other means ready to be photographed or traced onto the layout drawing.

Mural Boards.

Consider now that the planning department is actively engaged in preparing template laydowns for several shops and departments, the ultimate aim being, of course, the preparation and finalization of a composite layout embracing the entire factory.

At a certain period during the proceedings a number of laydowns of various departments will exist, all waiting to be co-ordinated into the complete layout. It is further likely that these smaller laydowns will need to be consulted jointly in order fully to appreciate the problem of co-ordination. Fig. 42 shows the interior of a large planning office where the use of mural boards has been introduced. Here several laydowns may be studied or discussed at any one time prior to their final placement in the plant layout as a whole.



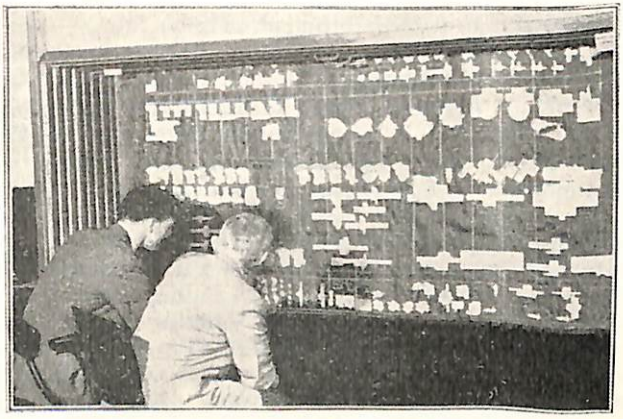
By courtesy of "Production Engineering and Management."

Fig. 42.

A suitable arrangement for the use of management is shown in Fig. 43, where several completed layouts are arranged on sashes, one in front of the other, and where any one of these may be pulled down for consultation in the manner of an ordinary window. By this means an executive may obtain a mental picture of any part of the works at will, without the necessity of moving from his desk.

Checking the Completed Layout.

It must be remembered that in layout work it is vitally important accurately to estimate and to provide for sufficient output capacity



By courtesy of "Factory Management and Maintenance."

Fig. 43.

at each work station in order to prevent bottlenecks at any one station along the line.

In the case of batch production where the cycle time condition does not apply similar estimates will act as a guide towards providing adequate storage areas for material in progress as well as raw material and finished goods.

When the layout is nearing completion an opportunity should be made for interested parties to view the project and to comment upon it. Representatives of outside suppliers of proprietary equipment should be invited, together with departmental heads within the works. Not until all parties are convinced that the layout is capable of producing as planned should the proposal be submitted to the management.

Effect of Present Conditions on Plant Layout.

In these days of serious building restrictions factory managements, in most cases, are obliged to confine their production activities to within the confines of existing buildings. This state of affairs is to be regretted but nevertheless the situation does offer to the active planning engineer a wide scope for ingenuity.

Consider a typical case study. The rate of production at a given factory is required to be increased by 30%. To achieve such a high overall increase no mere stepping up of speeds and feeds will suffice. Considerable replanning of operations and plant will be required. It may be necessary to install additional and faster types of machine tools and assembly areas. No building extensions are possible in which to house the increased capacity,

and additional floor space will have to be obtained by using the existing space but in a more efficient manner.

Apart from pallet stacking in stores and conveyorization, etc., which was described in Chapter VII, much may be done to increase productive area. Valuable space in many factories is wasted by the common conception of considering floor area as being two dimensional instead of three.

Most engineers of experience are familiar with the inefficient type of stores where material is stacked as received in its original containers or perhaps shot loose into bins. If of a suitable shape the goods might be seen propped against a wall or merely left lying on the floor. Almost invariably much "air space" is wasted, *i.e.*, that space from the top of the highest shelving or bin to the apex of the roof. Should mechanical stacking of material not be deemed justifiable there are usually very good reasons for replanning the stores area as a two or even three storey department in order to utilize to the maximum the cubic area that is available.

When laid out in this manner the stores would be staffed by placing one or more attendants on each floor who would pass material down to the counter staff for issue by means of a lift, dumb waiter or perhaps merely a simple gravity chute. The exact number and disposition of staff would depend upon the number of estimated calls likely to be made upon the stores during the course of a normal day or shift.

Where the issue of material from stores to departments is made by overhead conveyor the method is simplified to some extent. The problem then becomes one of not passing material out of stores downwards but of passing material to stores from the receiving deck in an upward direction.

In some cases where a factory is composed of several old buildings of varying designs cramped in a congested area the problem of thoroughfares between buildings becomes acute. With the advent during recent years of the fork lift truck with its attendant demand for wide gangways, the problem is further aggravated.

In a multi-storey building, admittedly not, in most cases, the optimum design for efficient production, material required to be moved, say, from the top floor in one building to another floor in an adjacent building should not need to travel in a lift to ground level, be transported a distance and then elevated again to the required floor in the next building. Bold use should be made of covered bridges and outside covered chutes or even underground tunnels if the factory site is deposed on the side of an appreciable hill.

Of no less importance is the consideration of reducing the space normally occupied by aisles, etc., inside buildings. Assuming the roof of the building to be a reasonable height, aisles intended solely for pedestrian traffic may be raised, perhaps ten or twelve

feet above the floor level of the shop, probably adjacent to a wall for convenience and economy, permitting extra plant and equipment to be installed in the vacant space thus created.

Should considerable vehicular traffic be required to traverse the shop, similar consideration might be given to the possibility of elevating a light assembly area or similar section. Canteens, offices, lavatories, etc., all lend themselves to elevation and an incidental advantage is obtained in that those services are rendered immediately accessible to all.

Where the height of the roof of the building precludes these structural alterations it may still be possible to erect an outside raised and covered walkway for pedestrian traffic, fire escape style.

In all structural work of this type due attention must be paid at all times to permissible floor loadings in the case of interior work and the possible restriction of amenities to third parties in the case of outside construction. A specialist consultant should be called in in all cases where any doubt exists.

APPENDICES.

TABLE 1.

JIG AND FIXTURE LOADING TIME.*

Type of jig or fixture	Time in seconds for Components weighing		
	Up to 2 lbs.	2 - 10 lbs.	Over 10 lbs.
Nut-cracker drill jigs	5	10	15
Vee block with stop. (for drilling, etc.) Small box jigs with no clamping or with cam clamping ... ... Increase times by 50% for batches of less than 50 off.	7	13	17
Milling Vise, toggle clamp or similar ...	4½	—	—
Milling Vise, hand crank	7	12	14
Open type jig with single location (with not more than two quick movements for clamping) ... ... Bridge type jig	13	22	37
Open and bridge type jigs, as above, but larger types and where spanner or tommy bar, etc., is necessary			
Most milling fixtures with spanner clamping	27	43	65
Box jigs and jigs requiring compound location, *e.g.*, spigot plus a radial location (2 clamps assumed)			
Add 11 secs. for each additional clamp ...			

*Loading time to be taken as a complete cycle, *i.e.*, load and unload. Table assumes well designed jig and fixtures in good condition. No accurate estimate can be given if assumption is otherwise.

The data given in Tables Nos. 1 - 5, 9, 10, 16 and 18 is the result of the author's experience in his own works. Contingency allowances will be found to vary slightly with the locality due to prevailing conditions.

TABLE 2.

DRILLING CONSTITUENTS.

Operation	*Time in Seconds*
Change drill in Jacobs chuck plus stop and restart m/c.	10
Change drill in No. 1 or 2 Morse taper socket	12
Change drill in No. 2 Morse taper socket and over ...	15
Lower drill into jig bush and release again after drilling	
(light work)	2
(heavy work)	5
*Ditto when holes widely spaced—light work	3
Ditto—heavy work	10
†Turning light jig over onto another face with one hand	1½
Turning heavy jig over requiring use of two hands ...	3 - 5
Man handling massive jigs	Up to 15
Turning jigs by lifting tackle	according to conditions
Change speed on drilling machine	Consult makers, a lot depends upon age of machine
Changing slip bushes	8
Changing back again	8
Clamping radial arm on pillar	5 - 10
Raise and lower tap, apply lubricant, occasional gauging	
¼″ dia.	5
½″ dia.	8
1″ dia.	12
1½″ dia.	15
Pick up part	1½
Blow out jig and lay part down	4

*Manipulation of jig under work is done simultaneously with lowering of drill, but with widely spaced holes may require extra time as shown.

†Time is for complete cycle, *i.e.*, turn over jig and return to original position.

30% contingency allowance

TABLE 3.

CENTRE LATHE CONSTITUENTS.

Operation	*Time in Seconds*
Place carrier on work, grease centre, place work between centres, adjust tailstock, complete cycle. (Light work using one hand)	30
*Ditto medium work using two hands	60
Place work on mandrel, place carrier on work or mandrel, grease centre, place mandrel between centres, adjust tailstock, complete cycle (light work using one hand)	50
*Ditto medium work using two hands	110
Change face plate for chuck or *vice versa*, small lathes ...	90
Ditto, medium lathes.	180
Chucking times :—(self-centring jaws, load and unload)	
Rough castings up to 2 lbs.	24
7 lbs.	34
20 lbs.	39
60 lbs.	46
Soft jaws gripping work already turned, up to 2 lbs. ...	19
7 lbs. ...	24
20 lbs. ...	29
60 lbs. ...	36
†Ditto but setting face true to ± ·001 in. 2 lbs. ...	37
7 lbs. ...	75
20 lbs. ...	120
60 lbs. ...	180
Chucking times (independent jaws, load and unload)	
Rough Castings, up to 2 lbs.	37
7 lbs.	42
20 lbs.	47
60 lbs.	54
Work clamped in turning fixture or face plate	See Table 4
Exchange tool in tool post and reset, light lathe	25
medium lathe ...	50
heavy lathe ...	80
Winding saddle along bed (time per foot travel)	6
Exchange tool bit in tool holder (according to size) ...	10 - 60
Fit steady on m/c. and set	8 - 12 mins.
Screw cutting—withdraw tool	3
reset	4
re-engage nut	2
Fitting up single gear train	10
Ditto with calculation	15
Fitting up compound gear train	15
Ditto with calculation	30
Set up complete, excluding fit steady if necessary,	
less than 24″ swing	20 mins.
24″ swing	30 mins.
over 24″ swing	40 mins.

*Work over 60 lbs. needs the assistance of a labourer or lifting tackle and must be judged according to facilities available.

†On small batches increase times by about 50%.

Contingency allowance 7½% - 15% depending upon opportunity for resting due to long, slow cuts, etc.

TABLE 4.

TURRET LATHE CONSTITUENTS.

Operation	*Capacity of Capstan or Turret Lathe*			
	1″	1½″	2″	3″ and over
Out Stock to stop and close collet	3	5	6	12
Withdraw hexagon turret and index	2	2	2½	9
Advance hexagon turret ready for cut	1½	2½	2½	5
Index square tool post	4	6	10	15
Withdraw square tool post :—				
(*a*) Transversely	2	3	5	8
(*b*) Longitudinally per foot ...	2	3	3	5
(*c*) Compound	—	4	4	6
Advance square tool post similar				
Withdraw rear tool post	2	3	5	8
Advance rear tool post similar				
Up part to standard collet ...	3	3½	3½	5
Up part to universal chuck ...	—	10	10	15
Up part to air chuck	2	3½	4	5½
Up part to face plate, or turning fixture, excluding clamping ...	—	4	4	5½
Clamping on face plate or in turning fixture :—				
Each thumb screw	—	2	2	2½
Each set screw or nut ...	—	3½	3½	4
Each quick acting clamp ...	—	1	1	2
Add (if necessary), locate clamp in dimple	—	3	3	3
Remove part from standard collet	2	2½	2½	4
,, ,, ,, universal chuck	—	5	5	7
,, ,, ,, air chuck ...	1	1½	1½	3
,, ,, ,, face plate or turning fixture not including release clamps	—	4	4	5½
Position part in split bush	2	2	2	3½
Remove part from split bush ...	1	1	1	3
Up file or de-burring tool, use and replace	2½	2½	2½	3
Change feeds	—	3	3	3
Change speeds	3	5	5	8

Contingency allowance 25% for setter-operator on large machine. 15% for operator on smaller machine with attendant setter.

TABLE 5.

MILLING CONSTITUENTS.

Operation	*Time in Seconds*
Start and stop machine	3
Rapid advance	5
Advance table by hand (per inch)	2
Raise or lower table by hand (per inch)	5½
Use feeler or shim for locating	5
Index dividing head (closely spaced holes)	3
,, ,, ,, (average spaced holes)	5
,, ,, ,, (compound)	8
Reset head	27
Blow off	3
Scrape swarf aside	3

Contingency allowance 15%.

TABLE 6.

POWER REQUIREMENTS FOR MILLING.

Material	*H.P to Remove 1 cu. in. per min*
Soft Steel	1¼
Tough Steel	1½
60-ton Tensile Steel	1¾
Cast Iron	¾
Soft Brass	½
Hard Brass	¾
Copper	1
Aluminium	¼

TABLE 7.

APPROACH OF CUTTER FOR END MILLS AND FACE MILLS.
(Cutter in Line with Work).

Diameter of mill in inches	Width of Cut in inches											
	1	2	3	4	5	6	7	8	9	10	11	12
1	·5											
1½	·192											
2	·135	1·0										
2½	·105	·5										
3	·09	·37	1·5									
4	·07	·27	·68	2·0								
5	·05	·24	·5	1·0	2·5							
6	·4	·18	·4	·77	1·34	3·0						
7½	·4	·14	·32	·59	·96	1·51	2·63					
8	·033	·13	·29	·54	·88	1·36	2·07	4·0				
10	·025	·10	·23	·43	·56	1·00	1·43	2·0	2·82	5·0		
12	·020	·08	·19	·35	·54	·81	1·13	1·53	2·04	2·69	3·6	6·0

These values are theoretical and $\frac{1}{16}$ in. to $\frac{3}{16}$ in. should be added to ensure cutter does not jab into work on rapid advance.

TABLE 8.

APPROACH OF CUTTERS FOR SPIRAL MILLS, KEYWAY CUTTERS, SAWS, Etc.

Diameter of Mill in inches	Depth of Cut in inches									
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	2
$1\frac{1}{4}$	·27	·37	·44	·50	·57	·612				
$1\frac{1}{2}$	·30	·41	·49	·56	·65	·71	·75			
$1\frac{3}{4}$	·32	·45	·54	·61	·72	·79	·87			
2	·35	·48	·58	·66	·78	·89	·97	1·00		
$2\frac{1}{4}$	·37	·52	·62	·71	·84	·93	1·06	1·12		
$2\frac{1}{2}$	·39	·54	·66	·75	·87	1·00	1·15	1·22		
$2\frac{3}{4}$	·41	·57	·69	·79	·94	1·06	1·22	1·32		
3	·43	·60	·73	·83	·99	1·12	1·30	1·41	1·50	
$3\frac{1}{4}$	·45	·63	·76	·87	1·04	1·17	1·37	1·50	1·62	
$3\frac{1}{2}$	·46	·65	·79	·91	1·08	1·22	1·44	1·58	1·73	
$3\frac{3}{4}$	·48	·67	·82	·93	1·13	1·28	1·50	1·66	1·84	
4	·49	·70	·85	·97	1·17	1·32	1·56	1·73	1·94	2·00
$4\frac{1}{4}$	·511	·72	·87	1·00	1·21	1·37	1·62	1·80	2·03	2·12
$4\frac{1}{2}$	·53	·74	·90	1·03	1·24	1·41	1·67	1·87	2·12	2·24
$4\frac{3}{4}$	·54	·76	·92	1·06	1·28	1·46	1·73	1·93	2·21	2·35
5	·56	·78	·95	1·09	1·32	1·50	1·79	2·00	2·29	2·45
$5\frac{1}{2}$	·58	·82	1·00	1·14	1·39	1·58	1·89	2·12	2·45	2·64
6	·61	·86	1·04	1·20	1·45	1·66	1·98	2·24	2·60	2·83
$6\frac{1}{2}$	·634	·89	1·09	1·25	1·51	1·73	2·08	2·35	2·74	3·00
7	·658	·93	1·13	1·30	1·58	1·80	2·17	2·45	2·87	3·16
$7\frac{1}{2}$	·68	·95	1·17	1·35	1·63	1·87	2·25	2·55	3·00	3·32
8	·71	·99	1·21	1·39	1·69	1·94	2·33	2·65	3·12	3·46
$8\frac{1}{2}$	·73	1·03	1·25	1·44	1·74	2·00	2·41	2·74	3·24	3·61
9	·75	1·05	1·28	1·48	1·80	2·06	2·49	2·83	3·36	3·74
$9\frac{1}{2}$	·77	1·08	1·32	1·52	1·85	2·12	2·56	2·92	3·47	3·88
10	·79	1·11	1·95	1·56	1·90	2·18	2·63	3·00	3·57	4·00

These values are theoretical and $\frac{1}{16}$ in. to $\frac{3}{16}$ in. should be added to ensure cutter does not jab into work on rapid advance.

TABLE 9.

LOADING TIMES FOR SMALL MAGNETIC CHUCKS.
(Small Ferrous Components).

Component Size in inches		*Time in Seconds*
Up to 2 sq. inch area	handled with one hand	3
,, ,, 10 ,, ,, ,,		4
,, ,, 20 ,, ,, ,,		6
Over 20 ,, ,, ,,		10
,, 20 ,, ,, ,,	handled with two hands	12

TABLE 10.

HANDLING TIMES FOR HORIZONTAL TYPE HOBBING MACHINES IN SECONDS.

Description	*Machine Capacity*	
	12 - 50 D.P.	4 - 30 D.P.
Chuck gear blanks	3	5
Chuck shaft	12	12
Set nut on work arbor and tighten ... ... (add 2 seconds per bush or washer)	9	9
Advance steady rest and tighten	7	12
Start machine	2	3
Advance carriage by hand	5	7
Engage feed	1	1
Clear carriage after cut	7	9
Loosen and back off steady rest	3	5
Remove work nut ... ... (add 2 seconds per bush or washer)	5	5
Remove gears and lay aside (any number) ...	4	6
Remove shaft and lay aside	9	9
Lower or raise work spindle	7	7
Change position of hob allowance	12	15
Change feed gears	90	90
Line up gears and mesh with hob ... ... (rough and finish using two hobs)	60	60

TABLE 11.

SPEEDS AND FEEDS FOR FELLOWS GEAR SHAPER.

Material	Speed No. of Strokes/min.		Feed	
	Roughing	Finishing	Roughing	Finishing
Steel	200	200	Fine	Medium
Cast Iron ...	200	200	Medium	Coarse

TABLE 12.

STROKES OF FELLOWS TYPE GEAR CUTTER PER INCH OF PITCH DIAMETER OF CUTTER. OR STANDARD CUTTER FEEDS.

Diameter of Cutter in inches	Strokes per Inch of Pitch Diameter of Cutter		
	Fine	Medium	Coarse
1	1390	955	721
2	695	477·5	360·5
3	463·3	318·3	240·3
3·5	397·1	272·8	206
4	347·5	238·8	180·2

TABLE 13.

SHEAR STRENGTHS OF MATERIALS.

Material	*Tons per Sq. in.*	*Material*	*Tons per Sq. in.*	*Material*	*Tons per Sq. in.*
Aluminium		Iron		Steel	
Cast	6	Cast	12½	·1 Carbon ...	22½
Soft	7½	2% Nickel ...	25	·25 Carbon ...	25
Half-Hard ...	9½	Wrought ...	20	·5 Carbon ...	35
Hard	12½	Lead	2	·75 Carbon ...	40
Asbestos		Leather		1·0 Carbon ...	42½
Millboard ...	2	Chrome ...	3½	1·2 Carbon not	
Brass		Oak	3⅓	Tempered	47
Cast	18	Rawhide ...	6½	1·2 Carbon	
Soft	15	Monel Metal		Tempered ...	95
Half-Hard ...	17½	Cast	30	Casting ...	30
Hard	20	Rolled Sheet ...	32½	Boiler Plate ...	30
Bronze		Nickel Silver		Angle Iron ...	30
Gunmetal ...	16	Half Hard ...	16	Cold Drawn Rod	29
Phosphor ...	20	Paper		Drill Rod ...	40
Copper		Hollow Die ...	1½	3½% Nickel ...	41
Cast	12½	Flat Punch ...	4¼	5% Nickel ...	42½
Rolled ...	14	Bristol Flat		Silicon ...	32½
Cupro Nickel ...	20	Punch ...	2½	Stainless ...	35
Duralumin		Strawboard		Tin	
Soft	15	Flat Punch	1¾	Cast	3
Treated ...	17½	Silver	15	Rolled ...	2½
Treated and				Zinc	
Cold Rolled ...	20			Sand Cast ...	7
Fibre				Die Cast ...	8
Hard ...	12			Rolled ...	9
				Hard Rolled	10

TABLE 14.

SHEARING PRESSURES REQUIRED FOR BLANKING.

Using Square Faced Punch.

Pressure required in tons, $P_1 = A \times T \times S$

where A = perimeter of blank in inches.
T = thickness of material in inches.
S = shearing pressure of material in tons per sq. in.

Using Single or Double Shear on Punch.

Pressure required in tons, $P_2 = \frac{P_1 \times R \times T}{Q}$

where, P_1 = pressure required, in tons, using square faced punch, *i.e.*, $A \times T \times S$, as above.
Q = Depth of shear on punch in inches.
R = Per cent. penetration of punch into metal.
T = thickness of material in inches.

Where holes are pierced in the same operation or during the same stroke as blanking, the sum of their circumferences should be added to the length of the blank outline for calculation purposes.

TABLE 15.

PRESS TONNAGE.*

(Allow 25% Safety Factor at Least).

Crankshaft Diameter in Inches	Tonnage	
	Single Crank Press	Double Crank Press
6½	150	150
7	180	180
7½	215	215
8	255	255
9	345	345
10	440	450
11	545	650
12	665	900
13	790	1150
14	920	1400
15	1060	1700
16	—	2000
16½	1300	—
17	—	2300
18	1560	2700
20	1950	—
22	2380	—
24	2860	—

Tonnage of single crank press with crankshaft 6 ins. diameter or less is given by,

diameter crankshaft in ins.^{2} × 3½ tons.

*Figures do not apply to end-wheel type presses having overhanging crankpin. For tonnage of these use formula,

diameter crankpin in ins.^{2} × 3 tons.

In all cases allow 25% safety factor, at least.

TABLE 16.

PRESSWORK CONSTITUENTS.

Operation	*Time in Seconds*
Pick up and insert strip, one operator	15
Ditto wide strip, *i.e.*, 6 ins. or over, one operator ...	20 - 25
Collect blanks and dispose of scrap in adjacent receptacle, where performed manually by operator, per strip ...	10
*Insert blank or pressing into die 4 ins. dia.	2
,, ,, ,, ,, ,, ,, 10 ins. dia.	3
,, ,, ,, ,, ,, ,, 18 ins. × 18 ins. ...	6
,, ,, ,, ,, ,, ,, 48 ins. × 18 ins. ...	10
Very large sheets, two or more operators	12 - 20
†Eject blank or pressing from die, similar to insert times	
Collect blanks and dispose of scrap, per pressing ...	2 - 5
Swing fly press, very light short swing	1
light swing	2
medium swing	4
long swing	8

*Times are applicable for thin gauge material and where location is simple.
†Except where inclinable press is used where times may be slightly less and where compressed air is used where times for small blanks is negligible.

Contingency allowance. 25% for short and medium batches.
30% for long runs necessitating tool changes.

TABLE 17.

POWER PRESSES.

AVERAGE STROKES PER MINUTE.

Maximum Pressure in Tons	Type of Press		
	Ungeared	Geared	Drawing
	Nature of Operation		
	Thin Gauge Material	Thick Gauge Material Drawing	Deep Drawing
10	120	—	—
20	100	50	30
40	80	40	35
60	60	30	20
100	30	15	10
150	20	10	7
200	15	8	5

Accurate figures cannot be given for large presses and in such cases reference should be made to the manufacturers.

TABLE 18.

PRESS TOOL SETTING TIMES.

Approx. Weight of Tools	No. of Men	Time in Minutes
56 lbs.	1	30
1 cwt.	2	30
2 cwts.	2	45
5 cwts.	3	60
10 cwts.	3	90
1 ton	4	120
2 tons	5 (includes crane driver)	120
5 tons	6	180
10 tons	6	240

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An up-to-date list of A.E.S.D. pamphlets in stock is obtainable on application to the Editor, *The Draughtsman*, Onslow Hall, Little Green, Richmond, Surrey.

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List of A.E.S.D. Data Sheets.

1. Safe Load on Machine-Cut Spur Gears.
2. Deflection of Shafts and Beams } Connected.
3. Deflection of Shafts and Beams (Instruction Sheet) }
4. Steam Radiation Heating Chart.
5. Horse-Power of Leather Belts, etc.
6. Automobile Brakes (Axle Brakes) } Connected.
7. Automobile Brakes (Transmission Brakes) }
8. Capacities of Bucket Elevators.
9. Valley Angle Chart for Hoppers and Chutes.
10. Shafts up to 5½-in. diameter, subjected to Twisting and Combined Bending and Twisting.
11. Shafts, 5¾ to 26 inch diameter, subjected to Twisting and Combined Bending and Twisting.
12. Ship Derrick Booms.
13. Spiral Springs (Diameter of Rd. or Sq. Wire).
14. Spiral Springs (Compression).
15. Automobile Clutches (Cone Clutches).
16. ,, ,, (Plate Clutches).
17. Coil Friction for Belts, etc.
18. Internal Expanding Brakes. Self-Balancing Brake Shoes (Force Diagram) } Connected.
19. Internal Expanding Brakes. Angular Proportions for Self-Balancing. }
20. Referred Mean Pressure Cut-Off, etc.
21. Particulars for Balata Belt Drives.
22. ¾" quare Duralumin Tubes as Struts.
23. ,, ,, ,, ,,
24. ¾" Sq. Steel Tubes as Struts (30 ton yield).
25. ⅞" ,, ,, ,, (30 ton yield).
26. 1" ,, ,, ,, (30 ton yield).
27. 1" ,, ,, ,, (40 ton yield).
28. ⅞" ,, ,, ,, (40 ton yield).
29. 1" ,, ,, ,, (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables) } Connected.
31. Moments of Inertia of Built-up Sections (Instructions and Examples) }
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart) } Connected
36. ,, ,, ,, (Sheet 2, Pitch Chart) }
37. ,, ,, ,, (Sheet 3, Notes and Examples) }
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors (Revised 1949).
41. Metric Equivalents.
42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles),
48. Solution of Triangles (Sheet 2, Oblique Angles).
49. Relation between Length, Linear Movement and Angular Movement of Lever (Diagram and Notes).
50. ,, ,, (Chart).
51. Helix Angle and Efficiency of Screws and Worms.
52. Approximate Radius of Gyration of Various Sections.

53. Helical Spring Graphs (Round Wire).
54. " " " (Round Wire).
55. " " " (Square Wire). } Connected.
56. Relative Value of Welds to Rivets.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. Graphs for Deflection of Rectangular Flat Plates of Uniform Thickness.
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart Showing Relationship of Various Hardness Tests.
64. Shaft Horse Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tangential Strain)
66. Ring with Uniform Internal Load (Tangential Stress) } Connected.
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain.
70. " " " Stress. } Connected.
71. Ring with Uniform External Load, Tangential Strain.
72. " " " " " Stress. } Connected.
73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities.
74. Journal Friction on Bearings.
75. Ring Oil Bearings. } Connected.
76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets, in accordance with B.S.S. No. 548/1934.
78. Velocity of Flow in Pipes for a Given Delivery.
79. Delivery of Water in Pipes for a Given Head. } Connected.
80. (See No. 105).
81. Involute Toothed Gearing Chart.
83. Variation of Suction Lift and Temperature for Centrifugal Pumps.
89. Curve Relating Natural Frequency and Deflection.
90. Vibration Transmissibility Curved or Elastic Suspension. } Connected.
91. Instructions and Examples in the Use of Data Sheets, Nos. 89 and 90.
92. Pressure on Sides of Bunker.
93-4-5-6-7. Rolled Steel Sections.
98-99-100. Boiler Safety Valves.
102. Pressure Required for Blanking and Piercing.
103. Punch and Die Clearances for Blanking and Piercing.
104. Nomograph for Valley Angles of Hoppers and Chutes.
105. Permissible Working Stresses in Mild Steel Struts with B.S. 449, 1948.
106. Compound Cylinder (Similar Material) Radial Pressure of Common Diameter (D1).

(Data Sheets are 3d to Members, 6d to others, post free).

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